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EDITED BY

OLIVER BYRNE,

EDITOR OF APPLETONS' 'DICTIONARY OF MECHANICS.'

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EDITORIAL NOTE.

In reporting progress, I have to state that the portion of this Dictionary now published is of sufficient extent to render apparent, by examples, the plan and scope of the whole work, the Second Division of which, contained in the present volume, supplies specimens of extensive articles on leading branches and important departments of engineering skill and industry. For instance, the article on Boilers, which treats of the generator of the motor Steam, occupies 90 pages, and is illustrated by 140 suitable engravings on wood; the article on Boring and Blasting extends over 85 pages, and is illustrated by 148 wood engravings. Brake, with its 69 cuts, makes 44 pages. In the present volume, Bridge and Bridge-building, with the accompanying 120 wood engravings, take up 150 pages. Many other articles might be named that occupy more space than one of the current semi-monthly parts. A slight inspection will show that this Dictionary will be amply illustrated, as the First and Second Divisions, occupying 768 pages, contain 1575 practical diagrams and working designs.

The practical mechanic or engineer—especially if he has neglected to study mathematics, abstract mechanical principles, chemistry, orthographic and other projections—should pay particular attention to the articles on Algebraic Signs and Atomic Weights; Acceleration, p. 7; Air-chamber, p. 34; Angle-brackets, p. 91; Angular Motion, p. 103; Boiler, pp. 395, 416; 425, 735; Boring and Blasting, p. 572; Brake, p. 618; Bridge, pp. 665, 683; *Note on Trigonometry*, p. 688; Spiral Surfaces, p. 728.

Many original investigations and solutions of important mechanical problems, not to be found elsewhere, are and will be given in this work; see pp. 46, 236, 429, 619, 629, 665, 764.

Among the subjects which will be immediately treated of I will name the following:—The Mining, Metallurgy, and Working of Copper; Coast Defences; Cotton Machinery; Casting and Founding; Cranes; Coal-working Machinery; Caisson; Cements; Concrete; Cams; Cork-cutting Machinery; Cask Machinery;

Chimneys and Chimney Shafts; Details of Engines; Drilling Machines; Dynamometers; Draw-Bridge; Distilling; Docks; Dredging Machines; Drainage; Diving Apparatus.

The proprietors of inventions and of important machinery in active operation, which possess phases of interest but little known, are invited to forward to me Plans and Descriptions of such specimens of skill and ingenuity that may appear suitable to the character of this work. Communications not made use of will be returned after the work is completed, and all contributors will receive due credit for their contributions.

OLIVER BYRNE.

The choice of a deck-line has everything to do with the usefulness of a ship for its purpose, more even than her behaviour at sea. This main or construction deck is, in small vessels, the uppermost deck, but in larger vessels there is a spar-deck above it; in a three-decker there are three decks above it, and in the GREAT EASTERN there are four decks above it and four below. As a general rule also, when a vessel is deeply laden, this deck is an eighth or a tenth of the beam of the ship above the water.

A little consideration of the purposes a main-deck has to serve will help to indicate how various its shape should be. In a vessel meant to be fast, one would wish its point to be like the rest of the bow of the ship, fine and sharp, because, if we put a full and bluff deck on the top of a fine fast bow, we not only give the vessel many bad qualities in pitching in a sea, but the fulness of the deck-line will be continually taking speed from the ship whenever the sea meets it, and so counteracting the very quality we meant to gain by giving a sharp bow under water. This argument in favour of sharpness appears at first sight inconsistent with the quality of a roomy fore-deck, which is to be obtained by a great, broad, bell-mouthed bow, flaring out wide over the surface of the water. Such a bow the old school and our Dutch neighbours dearly love and still believe in; and we should never have succeeded in introducing the fine sharp deck aloft, in opposition to the traditional prejudices and professional proverbs, in which the wisdom of seamen has come down to us, but for the fact, that the full projecting deck-line aloft has been found fatal to speed, and especially to speed in bad weather. There can be no doubt that in fine weather a large roomy bow on deck is a handsome and agreeable thing; all the work of the ship can be done in it comfortably and handily. There is room for everything, and to spare; nothing is huddled up, and you can get freely about everything: all this can be said with great plausibility and some truth, and it is still more applicable to a ship of war than to a merchantman, because, in chasing, it is desirable to lay two long guns parallel to each other in the line of the keel, and to be able to run them out through two bow ports, clear of everything, and to work them comfortably in that position. It was long pretended that it was impossible to do this on a sharp, fine deck-line, and for many years did Admiral Berkeley delay the improvement and stop the speed of our finest ships, for this crotchet, which in the end turned out to be a crotchet, and nothing more.

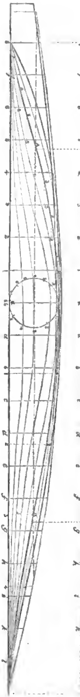
The simple fact is, that the roominess, dryness, and comfort of a full deck-line, instead of a fine one, is, impression or belief, and nothing more. If you imagine that a fine bow is got by cutting so much room off a full bow, and so diminishing the extent of available deck-room for working the ship, you may consider the fine bow as narrow, confined, and inconvenient; but the practical fact is the contrary to all this. The fine deck-line of a modern fast ship is not got by cutting anything off the length, or off the width, or off the roominess of a deck; the sharp bow is got by adding on a fine entrance to a bluff one, and by lengthening the deck: the full parts of the ship and of the deck remain where they were. All that is necessary, therefore, is to take care that the work and working parts of the ship shall, in the fine bow, be kept well back in the broad open space of the deck, and not crammed forward into the narrow space, which has been superadded, and which should be kept perfectly clear and unhampered. It is also a further peculiarity of the fine bow and fine deck-line, that the foremast stands much farther aft than in the old full bow, and that there is, therefore, more room before the mast: care must, therefore, be taken to keep windlass, capstan, catheads, anchors, and all the working parts in the bow, well aft,—not to give room merely, but also to keep heavy weight, as it always ought to be kept, out of the extreme bow of the ship.

There is another way of looking at this matter. I am very fond, says Russell, of covering in the whole of the fine part of a deck forward with a light forecastle bulkheaded off, especially in iron ships. It is a great convenience, and forms capital quarters for the crew: it keeps the head light and dry; and immediately abaft the forecastle a broad, roomy deck is still to be found. But there is another way of giving a roomy deck, that is, a wide one, on a sharp-bowed vessel. I have done it in vessels of war with perfect success, so as to make an extremely fine bow carry two long 8-in. guns parallel to the keel, through two comfortable ports, with ample room all round to work and train them freely. This I did by shortening the deck, or stopping it very much short of the bow, carrying the bulwark round the bow considerably behind the stem; the real deck beyond the bulwark forming part of the head, which, instead of being grated and overhanging the sea, had a solid oak deck over the greater part of it, leaving the head as convenient as before for all practical uses. In this way the bulwark of the deck left the real line of the ship 30 ft. short of the stem, with a fine, round, roomy deck to delight the heart of a commander of the old school, by giving him all he wanted on the inside, without impairing the form, which the sea demanded, on the outside.

There is yet another way of planting a full, round, capacious deck-line on a fine, hollow, fast water-line, and yet perfectly reconciling them to one another, so as to form a handsome, symmetrical, sea-going ship. This is to carry out the tumble-home bow. Of this system I am a warm advocate: it makes a vessel dry, easy, and safe. For a long time there has been much prejudice against it. The rising generation will probably adopt it largely; for the length and size of vessels will increase rapidly, and render it unnecessary to seek room by means of an exaggerated bow-line over a fine water-line. To carry out properly this system of tumble-home bow, it is only necessary to take a tolerably full, easy deck-line, composed of two circular or two parabolic arcs, laying them over the water-line, and so far behind it, as to be easily reconciled with it, by means of the cycloidal buttock-line; a process which will be guided, in a great measure, by the point at which the cycloidal buttock-line, already drawn, meets the level of the deck.

In the stern, there is even greater scope for management and fitting for use. I believe in large, capacious, roomy sterns. I think room can be got there with less cost and sacrifice than in any other part of the vessel; and hence the sterns of my ships have been called, by those who delight in small, narrow sterns, "Scott-Russell's ugly sterns." A small, handsome, light, little stern, may be eyesweet and pretty, but, to my mind, it is a costly whim. I scarcely know any good quality of a ship which is not improved, or any economy which is not enhanced, by a large, roomy stern and

826.



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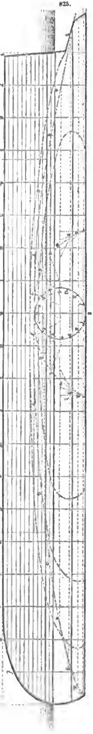

deck-line. In a merchantman it gives large passenger cabins, airy as well as roomy, and in that part of a ship which pays the owner best. In a ship of war it gives a magnificent roomy poop, and plenty of space for working the stern guns; which however are, perhaps, seldom wanted in a British ship of war. There is yet this further recommendation beyond all,—that the roominess and fulness of the stern in the neighbourhood of the deck-line is the greatest element of safety in the ship's most perilous position, of running before a heavy wind in a storm, and in most circumstances it may be used with advantage to enhance the stability and sea-going qualities of the ship.

The best way to turn the stern to advantage, for room and wholesomeness, is to carry the breadth on deck well aft, to taper the ship in towards the stern but little, and even, if necessary, to carry the projection of the stern a good way abaft and beyond the perpendicular, following, however, and not extending beyond, the vertical buttock-line already given. Here we may steal a great deal of room from the sea.

An early question arises: Shall we make the

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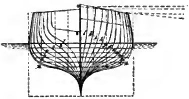
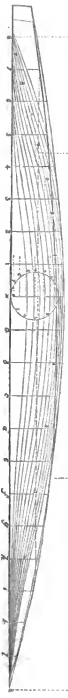


		Feet.
Length on load water-line	..	150
Breadth extreme	..	24
Depth at the side	..	16
Tonnage O.M.	..	415$\frac{4}{9}\frac{2}{4}$

stern round or square? I answer,—Its bulk is the main point: its shape is of less consequence. If you like, as a matter of taste, to cut the corners off, it becomes a round stern; and nothing is more common than to see people cut off the stern inside, and then stick something on the outside, to make up in appearance for the corners cut off. When very little is cut off the corners, it has been common to call it an *elliptical stern*, although it never is an ellipse; and when much is cut off, the stern is called *round*, although it never is circular. My own opinion about the precise outline of the deck astern is, that, so far as the qualities of the ship out of water are concerned, it is of little importance.

The constructor is now prepared to adopt a definite form for his deck-line, which is plainly a compound affair of policy, diplomacy, and taste. For a trial line I should use, forward, two arcs of a circle, intersecting at the bow, and having their centres on a line drawn athwartships, half-way between the perpendiculars; thence I should incline by two parabolic arcs, gradually narrowing to the breadth of the intended stern; and, for that breadth, I should adopt, at the point where it passes the perpendicular, some specific proportion—6, 7, or 8 tenths—of the midship breadth: finishing with whatever straight line or curve may have been determined on, as regards room at the stern. Indeed, in a vessel of no great

829.



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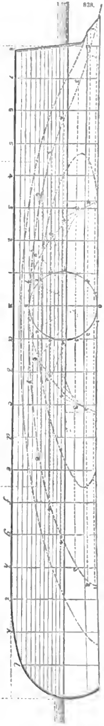


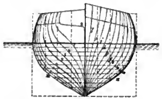
length, and without much overhanging counter, I cannot see any harm likely to arise from carrying the full breadth of the deck amidships right aft to the stern, with merely sufficient curvature to give an agreeable line.

The completion of the design now requires us to reconcile these four ruling lines of the ship with one another. In this operation, what the constructor must keep mainly in view, is to extend, as far as possible, through all the remaining lines of the ship, the good qualities which have been established in the ruling lines.

To Construct the remaining Water-lines.—It is most desirable that the water-lines of the entrance should be as exactly as possible of the same form, on reduced breadth, as the main water-line. There will be some difficulty in doing this, especially near the keel; and the tendency of these lines will be to elongate themselves forward. This is to be avoided.

The remaining water-lines of the after-body are to be constructed on nearly an opposite principle. They are to deviate rapidly from the chief water-line of the after-body already drawn; and

827.



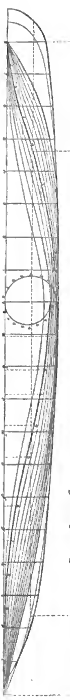
		Feet.
Length on load water-line	..	150
Breadth extreme	.. .. ..	24
Depth at the side	.. .. ..	16
Tonnage O.M.	.. .. ..	$415\frac{44}{94}$

this they will do naturally, because the main buttock-line, which rules the after-body, compels the water-lines to increase rapidly in fineness, as they go down in the water, and to extend rapidly in fulness, as they rise to the surface; thus giving what I believe to be the best kind of stern, namely, very fine below and very full above. In this respect it is a contrast to the bow, which is kept as full as may be, consistently with the chief water-line, all the way down.

It is desirable to have at least three complete water-lines, in order to form a first approximation to the complete calculation of the ship.

On the Completion of the Vertical Cross-sections, or Body-plan.—The cross-sections are all to be regarded as midship sections modified, but each of them giving, to the part of the ship where it lies, qualities which either enhance the good qualities of the midship section, or impair them. A vessel, with a fine, powerful midship section, may easily be impaired by feeble ends, and a weak midship section may be reinforced by good cross-sections, especially in the after-body. What the designer has to bear in mind, then, is to study how far he can enhance, support, and carry out the qualities of the main midship section in the rest of the body. In this attempt he will be materially aided by the choice which he makes of that cross-section which passes through the after-perpendicular. To this frame, being absolutely out of the water, he is free to give any

832.



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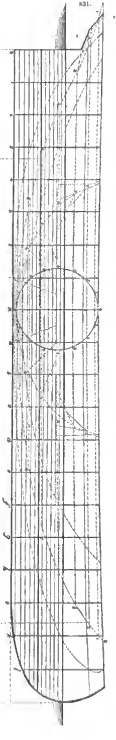
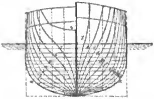


shape he pleases; and having fixed this, he will find that, with the main buttock-line, it rules the entire form of the after-body, and also controls materially the surface water-line of the stern. It is this stern cross-section which I am in the habit of making very full, in order to turn the after-body to the best possible account. Great caution, however, has to be observed, not to make this fulness abrupt; otherwise, when rising and falling in the sea, the counter will be apt to strike the water with violence.

The circumstance, that this portion of the vessel remains so entirely subject to the free will of the designer, makes it, for the inexperienced, the most difficult part to decide and determine; and a greater variety of forms will be found about the region of the stern above the water, than in any other part of a ship. The learner will, therefore, naturally be disposed to take this from the best examples he can find, and for which I refer him to the best vessels engraved in my work.

The vertical sections of the after-body, followed out in the manner I have indicated, will be found, as they approach the stern, to have become very fine below and very full above; and

830.



				Feet.
Length on load water-line			..	150
Breadth extreme	..	..	..	24
Depth at the side	..	..	..	16
Tonnage O.M.	..	..	..	415[illegible]

so they ought to be: but in the bow there will generally be found a similar tendency of the lines to become extremely fine below, and to grow full above,—and there it is necessary to counteract this tendency, instead of encouraging it, as abaft. The bow cross-sections must, therefore, be made to maintain their full breadth well down towards the keel; and care must also be taken that they do not spread out rapidly at the surface of the water, and above it. The reason why the fulness should be preserved below is, that the business of the fine part of the bow, or cutwater, is to displace or remove the water out of the way of that part of the ship which is to follow; and if the bow part be cut away too fine, this work will not be done, and the part behind will still have the work of displacement, with a bluffer entrance, and a shorter time to do it in,—which is the same as to say, that it would then require unnecessary force, by causing unnecessary resistance. The main water-line having, therefore, already rendered the bow sufficiently fine for the service of dividing the water, care must be taken not to carry this fineness further than necessary, or than it is carried in the chief water-line.

Moreover, much care will be needed to prevent the cross-sections of the bow from flaring out very much, to meet the line of the upper deck. To avoid this, we have recommended that line to be kept fine, and to be thrown as far backwards from

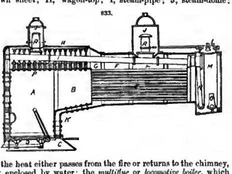
the fore-perpendicular as conveniently practicable. Moreover, the cycloidal buttock-line, properly used, will help to throw the deck back, and to prevent it from spreading over the fine bow: nevertheless, it will always be a matter of great difficulty to reconcile the wave water-line, the full deck, and the cycloidal buttock-line; but when it is well done, it makes the most beautiful, as well as the best, of all sea-bows. For fresh-water bows it does not matter how much the deck flares out, or how much it overhangs the water: it is in the sea that the true skill of the accomplished naval architect is to be developed. It is not the best voyage in fine weather, but the best behaviour in bad weather, which gives reputation to the truly seaworthy ship.

BOILER. Fr., *Chaudière à vapeur*; Ger., *Dampfkessel*; Ital., *Caldaia*; Span., *Caldera*.

A boiler is a strong metallic vessel, usually of wrought-iron plates riveted together, in which steam is generated for driving engines, or other purposes.

Fig. 833 is a section of a locomotive boiler; A, fire-box; B, combustion chamber; D, grate; C, ash-pan; K, water-legs; P, crown sheet; H, wagon-top; I, steam-pipe; J, steam-dome; G, gusset; F, barrel; E, flues; N, breeches-pipe; M, smoke-box; L, saddle; O, blast-pipe; R, dry-pipe.

833.



A *steam boiler* generally consists of a fire-box, where the combustion of *fuel* occurs, and flues, through which the products of combustion pass into the chimney. These parts are made of thin metal, and surrounded by water, which, together with the steam room, is contained in an outer shell. The principal varieties of boilers are,—the *cylinder boiler*, which consists of a single iron shell; the *return-flue* and the *drop-flue* boilers, called *flue boilers*, which are single shells containing a small number of large flues, through which the heat either passes from the fire or returns to the chimney, and sometimes containing a fire-box enclosed by water; the *multiflue* or *locomotive boiler*, which consists of an enclosed fire-box and a large number of small flues leading to the chimney; and the *water-tube boiler*, which consists of an enclosed fire-box and a fire-chamber filled with small tubes, through which the water circulates. *Tubular boiler, a multiflue* or multitubular boiler, in distinction from a boiler with large flues.

Copper, when the temperature of the steam does not exceed 200° Fahr., is the best material for boiler construction, its power of conducting heat being nearly double that of iron; a copper boiler of only one-half the superficial contents of an iron one will generate a similar quantity of steam. The power of copper in conducting heat is about 898·2, and that of iron 374·3. Iron possesses the greatest cohesive strength, yet manufacturers generally construct their copper boilers of thinner metal on account of the greater uniformity in the substance of copper plates as well as for the sake of economy, copper being five times the cost of iron; but an old worn-out boiler is worth three-fourths its original value, whereas the value of an old iron one is comparatively trifling when the cost of removal is deducted. Copper has also been proved to be the safest: when a copper boiler bursts or explodes it is merely rent open, but an iron boiler is generally blown to pieces.

834.

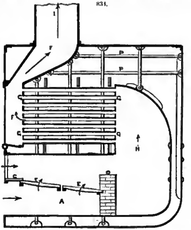


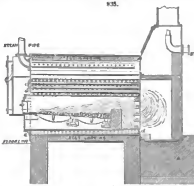
Fig. 834, which is a longitudinal section of a marine tubular boiler, shows the general arrangement of parts in a marine boiler. A is the ash-pit; C dead-plate; E E the grate; F F the uptake; G G the tubes and tube-plates; H the back uptake, flame-chamber, or rising flue; I the chimney; O the bridge; and P P stay-rods.

The boiler shown in Figs. 835, 836, 837, is according to an arrangement invented by David Thomson, and successfully introduced by Richard Moreland and Sons, London.

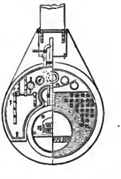
Fig. 835 represents a longitudinal section, and Fig. 836 a front elevation and cross-section of a Thomson boiler, 8 ft. long and 5 ft. 6 in. diameter, having the same amount of heating-surface as an ordinary Cornish boiler 27 ft. long and 5 ft. diameter, with an internal fire-tube 2 ft. 9 in. diameter. Fig. 837 is a front elevation and cross-section of a boiler, 8 ft. long and 8 ft. diameter, having as much heating-surface as the very largest sized double-flued Cornish boiler 33 ft. long and 7 ft. diameter. The fire-chamber is the same as in Cornish boilers, and is fitted with the usual furnace door and adjustable slide to admit air over the fire for the combustion of the smoke. The ash-pit is also fitted with a door,

by means of which the draught can be regulated. The products of combustion, after passing the fire-bridge, make their way through perforated fire-brick into a roomy chamber lined with fire-brick, and thence pass through the small tubes to the front smoke-box, from which they return

835.

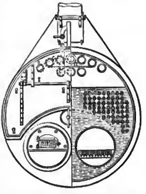


836.



through the larger tubes to the chimney, superheating and drying the steam in their passage. The steam-pipe extends internally over the whole length of the boiler, and is pierced with small holes, which cause it to take the steam equally from all parts of the boiler, while the steam is compelled by the plate *a*, Figs. 835 to 837, to pass over the heated surface of *all* the large tubes before reaching the steam-pipe. Ogle, of whom we shall hereafter speak, introduced this description of steam-pipe in some of the later arrangements of his boiler. When the boiler is used for non-condensing engines, it is advisable to bring the exhaust-pipe of the engine to the bottom of the chimney, as at *b*, Fig. 835, where it serves to stimulate the draught. But provision is made for increasing or regulating the draught to any extent by a steam jet-pipe *c*, Figs. 836, 837, having a small hole opposite the centre of each of the large tubes, by which a jet of steam can be projected through it. This method of applying the steam jet to increase the draught is found to be much more certain, powerful, and economical than when applied in the chimney.

837.



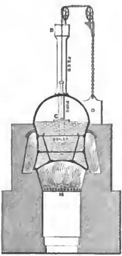
This boiler, constructed by the Morelands, is short and of large proportional diameter, and from its circular form is well adapted for high pressures. There is also a large amount of heating-surface within a small bulk, and no boiler-seating is required; hence it is a boiler suitable for situations where space is limited, or when it is desirable to reduce the cost of fixing and of brickwork.

The wagon-boiler, Figs. 838, 839, is used for generating low-pressure steam only.

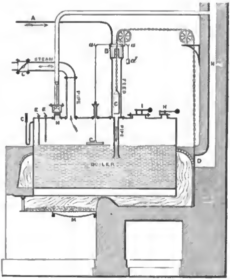
In Figs. 838, 839, which are transverse and longitudinal sections respectively, A is the supply-pipe from the hot well terminating in the cistern at the top of the feed-pipe; B cistern at the top of feed-pipe, having a valve fixed at the bottom; C the float employed to regulate supply of water to boiler. The water is kept at the same height by its action upon the valve at the bottom of the feed-pipe; thus, when there is not sufficient water in the boiler, the float sinks, pulls down the arm of the lever *a a* to which it is attached, and opens the valve, since the counterbalancing weight *d* fixed at the other end of the lever will only support the float when in its proper situation in the boiler and at the required level of the water. D is a self-acting damper for regulating the consumption of fuel; E E gauge-cocks; G steam-gauge; H safety-valve, regulated by the engineer; I air-valve, or atmospheric safety-valve; U the locked safety-valve. A pipe is shewn at the top which leads the steam that escapes into it to the flue or into the air. The steam passes from the boiler through the steam-pipe; a valve, called a throttle-valve, L, being placed in it for regulating the amount of steam to the cylinder; M furnace-bars; N the flue; S, S stays.

Figs. 840 and 841 represent longitudinal and transverse sections respectively of the Whittle boiler. *a*, *a* are the plates forming the body of the boiler; *b*, *b* the inner casing or lining; *c* is the circulating space between the inside of the boiler and casing, *b*. When heat is applied to the outside of the boiler *a*, the water in the space *c* is first heated, and commences to ascend in the space *c*; and as the heat increases, a rapid circulation of the water and steam takes place up the heated sides of the boiler. When the water and steam reach the upper edge or lip of the casing *b* (which extends a little above the water-level), the steam is separated from the water, which steam occupies the upper part of the boiler; but the water boiling over the edge of the lining or casing *b* into the central part of the boiler, descends through the short upright pipes *d d* through the bottom of

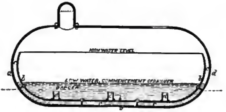
838.



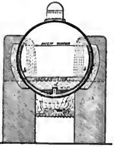
839.



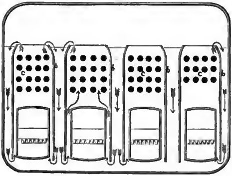
840.



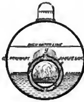
841.



843.



842.



the lining into the space c, and thus maintains a continuous circulation so long as heat is applied. The mud carried over settles on the bottom of the lining, as shown in the figures, where it is retained, thus preventing the formation of deposit on the plate of the boiler. By this arrangement, the boiler is kept clean and not liable to rapid incrustation. When Cornish or fluid boilers are used, as shown in Fig. 842, the flues are surrounded by a casing $e\,e$, the circulation taking place up the space $f\,f$, the hot water and steam being delivered at the opening g, as shown in the drawing.

Fig. 843 represents the application to a marine steam-boiler, where $b\,b$ are the linings or diaphragms between the series of flues $c\,c$ of the boiler. By the use of these linings or diaphragms b a steady circulation of the water in the boiler is set up, and the mud and deposit are, in consequence, made to accumulate at the bottom of the boiler, from whence it may be blown off.

Before giving an extensive analysis of the different arrangements of locomotive, marine, and other boilers, designed to effect particular objects, it is necessary to point out some of the leading properties of heat, water, and steam, determined by abstract reasoning and corroborated by experiment.

Caloric Capacity of Bodies. *Unity of Heat.*—In observing the general mode in which bodies become heated, we recognize this fact, which may be said to be purely external, that in order to bring different quantities of a same substance to a same temperature, the same combustible being used, the weights of the latter must be proportional to those of the substance.

For example, if 10 kilogrammes of coal are requisite to raise the temperature of a certain weight of water from 0 to 20 degrees—the conditions remaining unaltered—it will take 20 kilogrammes to perform the same operation upon twice that weight of liquid.

The reduction of this observation to the accurate data of science led to the following positive result, namely: That, to raise a same weight of a same homogeneous and determinate substance one degree in temperature, the expenditure of a same quantity of heat is invariably necessary. And moreover, with certain restrictions: That the quantities of heat required are proportional to the weight of that same body and to the increase of temperature.

This being once established, it became easy to create a representative value capable of serving as unity of comparison in the various interchanges of heat that take place between different bodies, and of enabling us, also, to estimate the quantities of heat supplied by calorific sources. For that purpose it was sufficient to select some homogeneous substance, and to adapt, as point of comparison, that exact amount of heat that was required to raise its temperature by a given value.

Acting in accordance with these principles, that quantity of heat which is necessary to increase the temperature of one kilogramme of water by one degree centigrade is what has been adopted as the unity, and serves to compare all the interchanges of heat that are observed.

Consequently, if we take a kilogramme of water at zero, and raise it to the temperature of one degree, we say we have given it one unit of caloric; if to two degrees, two units; and so on. In like manner, one kilogramme of water, at any temperature above zero, is considered to possess as many units of caloric as it has degrees of temperature.

We are here speaking of water in its liquid state, and of its heat in so far as it is sensible to the thermometer, but not of the total amount of heat it in reality possesses at a given temperature. We shall hereafter see that the greater part of the heat contained in a body is *latent* and constitutive of its liquid or gaseous state.

Let us, as an example, suppose a red-hot bullet to be plunged into a vessel of water, and then observe the increased temperature derived by the latter from the cooling of the bullet, as it abandons its heat in favour of the liquid. By taking into consideration the water only, and setting aside the losses of caloric occasioned by evaporation and radiation, it will be easy to estimate the amount of heat gained by the liquid mass, by means of its actual weight and increased temperature.

From what has just been said of the connection that exists between the temperatures in degrees and the quantities of heat, if 50 kilogrammes of water, at the temperature of 12 degrees, acquire a temperature of 45 degrees by the immersion of a heated body, the quantity of caloric gained by the water will be ascertained by finding the product of the difference of the observed temperatures by the weight of the mass expressed in kilogrammes.

Let W be the weight of water in kilogrammes;
t be the original temperature;
t' be the increased temperature;
n be the number of units of caloric gained;

we have

$$n = (t' - t)\,W;\ \text{whence}\ n = (45 - 12)\ 50\ \text{kilos.} = 1650\ \text{units.}$$

The reasoning would be precisely the same if it were required to find the number of units of caloric lost by the immersion of a body colder than the water.

If, for example, we plunge a very cold body into 50 kilogrammes of water at 45 degrees, and that, the temperature being thereby reduced to 10 degrees, we wish to know how many units of caloric have been lost by the water after the equilibrium has been restored, we have, as before,

$$n = (45 - 10)\ 50 = 1750\ \text{units.}$$

Specific Heat.—A body is said to have a greater or less capacity for heat, according as it requires a greater or less amount to cause its temperature to vary an equal number of degrees. If, by comparing two equal weights of two different substances, it be found that, in order to increase their respective temperatures by one degree, it takes twice the quantity of heat in the one case that it does in the other, we conclude that the calorific capacity of the one mass is double that of the other. By representing, therefore, the smaller capacity by 1, we may represent the larger by 2.

The calorific capacity may likewise be characterized by observing the ratio of the temperatures acquired by equal masses of different substances to which equal quantities of heat have been communicated; the coldest evincing, necessarily, the greatest calorific capacity. Moreover, the

numerical ratios of those capacities will be represented by the temperatures expressed in degrees, but in inverse proportion.

For instance, supposing that we plunge three equal bullets, of the same metal, and heated to the same temperature, into three equal volumes of different liquids, and afterwards find that the temperatures of those liquid masses have been respectively raised 1 degree, 2 degrees, 3 degrees; it may be said that their calorific capacities are inversely proportional to these increments of temperature, that is, as 3 : 2 : 1.

So that the calorific capacity of a body, or its *specific heat*, is represented by a number, similar to a coefficient, and which has reference to the unity for which the specific heat of a certain substance serves as standard.

For liquids and solids the standard chosen is water, the unity of heat corresponding, as we have already stated, to that quantity which is necessary to raise the temperature of 1 kilogramme of water 1 degree.

In the case of gases, atmospheric air has been selected as the standard of comparison; but water must, nevertheless, also be used, so that absolute practical values may be obtained.

When we wish to find the respective calorific capacities of gases, we compare them, one with another, in equal volumes, but under two different conditions.

When a gas is heated, it expands, and tends to increase its volume. If it be subject to a constant pressure, that augmentation takes place freely, according to the value of its coefficient of expansion. If, on the contrary, the space that it occupies be inextensible, its volume remains the same, but its pressure increases. It has, consequently, been the preoccupation of physicists to ascertain whether, under these two conditions, the calorific capacities of gases might not be different; and that is why the Tables, giving the results of their labours, show two columns, based upon the foregoing consideration.

From the purely practical point of view we are now taking of the subject, this distinction is, perhaps, not of any very great importance, especially as the differences themselves are not very considerable; but it was necessary that we should mention it, in order that the following Tables, borrowed from the illustrious *savants* to whom we are indebted for these useful researches, may be better understood.

We must further state that it is our intention to cite such substances only as are susceptible of being employed in the organs of motion about to occupy our attention.

To render these Tables perfectly intelligible, it will be sufficient if we define clearly what is meant by the numerical value of the coefficient of specific heat, or simply, by the calorific capacity of a body.

It being agreed to term *unity of heat* that quantity of caloric which increases by 1 degree the temperature of 1 kilogramme of water, comparisons were made with a large number of substances, and it was found that that same amount of heat produced, in every kilogramme, modifications of temperature that differed widely, according to the substance to which it was applied; and that, in nearly all cases, the elevation of temperature was much more considerable than that of the water.

But this very definition of calorific capacity tends to show that the ratio between the increased temperature of the water, that is to say, one degree or unit for every kilogramme, and the increase of temperature of the substance under consideration, is precisely equal to the inverse ratio of the capacities of that substance and the water.

Consequently, if c represent the capacity of water and t its increased temperature, c' the capacity of the substance to be compared and t' its increased temperature, we shall have

$$t : t' :: c' : c, \text{ or } \frac{t}{t'} = \frac{c'}{c}.$$

But the value of both t and c being the unity, the capacity c' of the given substance is

$$c' = \frac{1}{t'}.$$

Whence we derive the following definition:

The numerical value c' of the coefficient of specific heat of a determinate substance is equal to the quotient of the unity divided by the increase of temperature produced by one unit upon one kilogramme of that substance.

The values inscribed in the following Tables are precisely the aforesaid quotients for each corresponding substance. A little later we shall give a few examples of the use of these values.

TABLE I.—CAPACITIES OF GASES.

Ascertained by MM. Delaroche and Bérard, those of air and water being taken as unity.

Names of Gases.	Calorific Capacities, that of Air being 1 for		Capacities for equal Masses, Water being taken as unity.	Ratio of Capacities for	
	Equal Volumes.	Equal Masses.		Constant Volumes.	Constant Pressures.
Atmospheric air	1·000	1·000	0·2669	1·421	1·00
Hydrogen	0·9035	12·3401	3·2936	1·407	1·00
Oxygen	0·9765	0·8848	0·2361	1·415	1·00
Steam	1·9600	3·1360	0·8470	According to Dulong.	

By this Table it is seen that, weight for weight, hydrogen is the most difficult gas to heat, since it requires twelve times more caloric than atmospheric air to raise it to an equal temperature.

After hydrogen comes steam, whose capacity is almost double that of air, and very nearly equivalent to that of water.

The two last columns of the Table indicate, according to Dulong, the variations undergone by the calorific capacities of the corresponding gases, whether they be considered under constant volumes or constant pressures while submitted to the influence of heat. We see that, the pressure being constant, the capacity varies from 1 to about 1·4, if the gas is compressed by the effort of expansion that takes place during heating.

However, this question is far too complicated for us to give it full extension here; we have thought proper, therefore, merely to mention it by the way, referring those of our readers who are desirous of more deeply investigating it to special works upon the subject.

Table II.—Calorific Capacities of Various Substances.

That of water being taken as unity.

Names of Substances.	Calorific Capacities.	Observations.
Water	1·0000	
Iron	0·1100	Dulong and Petit.
„ from 0° to 100°	0·1098	„ „
„ „ 0° „ 300°	0·1218	„ „
Cast iron	0·1298	Regnault.
Steel	0·118 to 0·127	„
Copper	0·0949	Dulong and Petit.
„ from 0° to 100°	0·0940	„ „
„ „ 0° „ 300°	0·1013	„ „
„	0·09515	Regnault.
Brass	0·09391	„
Lead	0·0293	Dulong and Petit.
„	0·0314	Regnault.
Tin	0·0514	Dulong and Petit.
„	0·05623	Regnault.
Zinc	0·0927	Dulong and Petit.
„	0·09555	Regnault.
Glass from 0° to 100°	0·1770	Dulong and Petit.
„	0·1900	
„ from 0° to 300°	0·19768	Regnault.
Charcoal	0·2415	„
Coal and coke (average)	0·20	„
Woods, various	0·600 to 0·650	Mayer.

This second Table, relating to the calorific capacities of the principal substances used in construction and manufactures, shows that, of them all, water possesses the greatest, and is, consequently, the most difficult and the most expensive to heat. The next is wood, and that which has the smallest capacity is lead.

Application of the Coefficients of Calorific Capacity.—The knowledge of the calorific capacities of bodies, and their representation by numerical values, lead to problems that are both highly interesting and extremely useful in their application. The principal ones may be summed up as follows:—

1st. Find the quantity of heat necessary to raise the temperature of a body a given number of degrees; and reciprocally, how much heat must be withdrawn in order to lower its temperature in the same proportion.

2nd. Find the temperature of a mixture, whether the bodies be equal or unequal in mass and calorific capacity.

3rd. Find the effects of expansion produced by given quantities of heat upon gases or vapours.

We will endeavour to illustrate by a few examples these different modes of treating the question; reserving, however, for later, further particulars relating to expansion, which may be more particularly interesting when we come to speak of superheated steam and of motors worked by gases.

Researches as to the Quantity of Heat corresponding to a given Variation of Temperature.—It has been seen, from the definition of capacity and the unity of heat, that the amount of caloric a body loses or gains, according as it becomes heated or chilled to a given number of degrees, is proportional both to its mass and to its calorific capacity; since, if 1 kilogramme of water absorbs 1 unit in order to gain 1 degree in temperature, it would absorb 2 units for 2 degrees, and so on; or else, 2 kilogrammes would absorb 2 units for 1 degree: finally, 1 kilogramme of a substance whose specific heat is 0·5 would absorb half a unit to raise its temperature 1 degree, and so on. Consequently, the general formula for heating and cooling is this:

$$n = t\,W\,c, \text{ or } n = (t' - t)\,W\,c, \qquad [A]$$

$t' - t$, or simply t, being the difference of temperature, or the number of degrees gained or lost.

First example.—How many units of heat would be absorbed by 50 kilogrammes of water at 15 degrees, that its temperature might be increased to 60 degrees?

$$n = (60 - 15) \times 50 \times 1 = 2250 \text{ units.}$$

The result would evidently be the same in order to lower the temperature from 60 degrees to 15 degrees.

Second example.—If 3000 units of heat were supplied to 500 kilogrammes of water, what would be the increase in its temperature?

By the preceding formula we have

$$t = \frac{n}{W c}; \text{ whence } t = \frac{3000}{500 \times 1} = 6 \text{ degrees.}$$

Third example.—How many units of caloric are given out by 100 kilogrammes of iron when, in cooling, its temperature is lowered 200 degrees?

The preceding Table indicates that the calorific capacity of iron is 0·11, therefore

$$n = 200^\circ \times 100^k \times 0 \cdot 11 = 2200 \text{ units.}$$

Fourth example.—When 100 kilogrammes of a body give out 1000 units of heat in cooling, and its temperature is lowered 55 degrees, what is its calorific capacity?

From the same formula whence we derived the value of t, we also obtain

$$c = \frac{n}{t W}; \text{ or } c = \frac{1000}{55 \times 100} = 0 \cdot 1819.$$

To Find the Temperature of a Mixture or Compound.—This problem is susceptible of various solutions, according as the capacities of the substances compounded are equal or different. We will give examples of both cases. It is possible, however, to establish a general formula, that will only be simplified if the masses or capacities are equal.

If two substances be compounded whose weights are W and W', the temperatures t and t', and the capacities c and c', there will result a final temperature x, to find which we reason thus:

After mixing, the two masses will have acquired an even temperature; the one will be a certain number of degrees colder, represented by $t - x$, whence the number of units it will have lost will be $= (t - x) W c$; while the other, on the contrary, will have acquired an accession of calorie $(x - t') W' c'$.

But since that which was lost by one of the masses has been gained by the other, these two quantities are equal, and give the following equation:

$$(t - x) W c = (x - t') W' c', \qquad [B]$$

from which we obtain

$$x = \frac{t W c + t' W' c'}{W c + W' c'}, \qquad [C]$$

x being the required temperature of the compound.

It is evident, however, that when the masses or the capacities are equal, the symbols whereby they are represented must be eliminated from the foregoing expression. For instance, if the masses of the bodies compounded were equal, we should have W = W'; and the relation would assume the following form: $\frac{t W c + t' W c'}{W c + W c'}$; whence we have $\frac{(t c + t' c') W}{(c + c') W}$, where W necessarily disappears, leaving

$$x = \frac{t c + t' c'}{c + c'}, \qquad [D]$$

that is to say, the mass is not to be considered.

If the capacities were equal, the same operation would be performed with respect to c and c' which would disappear, the formula taking the shape

$$x = \frac{t W + t' W'}{W + W'}. \qquad [E]$$

Finally, if the masses and the capacities both happened to be equal, the expression would then be reduced to the following:

$$x = \frac{t + t'}{2}. \qquad [F]$$

It will be seen that the foregoing first general expression [B] suffices to find the temperature of a compound under every condition. We may even suppose the form reversed, and that it be proposed to find the requisite proportions of a compound in order to obtain a given temperature. We will give a few examples of each particular case.

First example. Equal masses and equal capacities.—Find the temperature x of a mixture of two equal masses of water, the one at a temperature $t = 25$ degrees, the other at a temperature $t' = 40$ degrees.

Formula [F]:

$$x = \frac{t + t'}{2} = \frac{25^\circ + 40^\circ}{2} = 32 \cdot 5 \text{ degrees.}$$

Second example. Equal capacities.—What will be the temperature of a mixture of 10 kilogrammes of water at 12 degrees and 15 kilogrammes at 50 degrees?

Formula [E]:

$$x = \frac{t W + t' W'}{W + W'} = \frac{(12^\circ \times 10) + (50^\circ \times 15)}{10 + 15} = 34 \cdot 8 \text{ degrees.}$$

Third example. Equal masses.—500 kilogrammes of water at 90 degrees are poured into a copper vessel of the same weight and a temperature of 15 degrees; find the temperature of both vessel and water, at the moment of equilibrium, supposing that there are no losses of caloric.

Formula [D]. By the Table we find the capacity of copper to be 0·095. Consequently, we have

$$x = \frac{t c + t' c'}{c + c'} = \frac{(90^\circ \times 1) + (15^\circ \times 0 \cdot 095)}{1 + 0 \cdot 095} = 83 \cdot 5 \text{ degrees.}$$

So that the temperature has only fallen $6°\cdot5$, to raise that of the 500 kilogrammes of copper from 15° to $83°\cdot5$: this is owing to the enormous difference between the capacity of water and that of copper.

Fourth example. All conditions differing.—A mass of iron weighing 150 kilogrammes, and at a temperature of 300 degrees, is plunged into 100 kilogrammes of water at 10 degrees; what will be the temperature of the water when equilibrium of temperature has been established?

The different data of the problem stand thus:

Capacities	Water	$c = 1$
	Iron	$c' = 0\cdot11$
Temperatures ..	Water	$t = 10°$
	Iron	$t' = 300°$
Weights	Water	$W = 100^k$
	Iron	$W' = 150^k$

Formula [C]:

$$x = \frac{t\,W\,c + t'\,W'c'}{W\,c + W'c'} = \frac{(10° \times 100^k \times 1) + (300° \times 150^k \times 0\cdot11)}{(100^k \times 1) + (150^k \times 0\cdot11)} = 51\cdot07 \text{ degrees.}$$

Fifth example. Mixture of gases.—The preceding rules apply equally to the mixtures of bodies whose quantities are expressed by their volumes. Thus it has been already seen that the relative capacities of gases have been ascertained in this manner, by taking atmospheric air as the unity.

We propose, therefore, to find the temperature x of a mixture of two volumes of hydrogen and oxygen under the following conditions:

Capacities	Hydrogen	$c = 0\cdot9035$
	Oxygen	$c' = 0\cdot9765$
Temperatures ..	Hydrogen	$t = 10°$
	Oxygen	$t' = 45°$
Volumes	Hydrogen	$V = 1^{mc}$
	Oxygen	$V' = 0^{mc}\cdot800$

Formula [C]:

$$x = \frac{V\,t\,c + V'\,t'c'}{c\,V + c'\,V'} = \frac{(1^{mc} \times 10° \times 0\cdot9035) + (0^{mc}\cdot800 \times 45° \times 0\cdot9765)}{(0\cdot9035 \times 1) + (0\cdot9765 \times 0\cdot800)} = 26°\cdot2.$$

To Find the Proportions of a Mixture.—It is as frequently required, in practice, to ascertain in what proportion a mixture ought to be compounded so as to have a certain temperature, as it is to perform the inverse operation: and, although the only thing necessary for that purpose is a suitable adaptation of formula [B] or [C], involving no difficulty, we will, nevertheless, give a few more examples.

First example.—Given a mass of lead weighing 75 kilogrammes, at 150 degrees, in what body of water at 12 degrees should it be plunged in order that the whole exceed not 20 degrees at the moment that the equilibrium of temperature is established between the liquid and the metal?

The unknown quantity, this time, is the weight W of the mass of water; and, if we retain the same notation as in formula [B], x, the temperature of the mixture, will equal 20 degrees. Consequently, the fundamental formula [B] being $(t - x)\,W\,c = (x - t')\,W'c'$, we easily extract from it the value $W = \dfrac{(x - t')\,W'c'}{(t - x)\,c}$, which becomes the general expression applicable to all problems of the nature of the one above proposed, and of which we will now give the solution. It must be observed, however, that in this particular case, where t' is greater than x, and x is greater than t, it would be as well to transpose the complex quantities between brackets in order not to have negative values, which should, nevertheless, not affect the result: on the other hand, as x is no longer the unknown quantity, we shall replace it by the sign T, to indicate the given temperature of the mixture.

The foregoing expression, thus modified, then becomes

$$W = \frac{(t' - T)\,W'c'}{(T - t)\,c}, \qquad [G]$$

and if we introduce into this formula the several data of the problems, together with the calorific capacity of lead $= 0\cdot0293$ (second Table), we find that the body of water required is

$$W = \frac{(150° - 20°)\,75 \times 0\cdot0293}{(20° - 12°) \times 1} = 35\cdot709 \text{ kilogrammes.}$$

The relative smallness of this weight of water is perfectly in accordance with the small calorific capacity of lead, which is about the three-hundredths of that of water.

Second example.—What weight W of cold water, at $t = 12$ degrees, must be added to W', $= 100$ kilogrammes of the same liquid, at $t' = 80$ degrees, so as to obtain a mixture T, $= 20$ degrees?

As here the capacity is the same for both masses, the formula [G] becomes

$$W = \frac{(t' - T)\,W'}{(T - t)}; \text{ whence } W = \frac{(80 - 20) \times 100}{20 - 12} = 750 \text{ kilogrammes.}$$

These examples will be sufficient to show the utility and the application of the coefficient of specific heat; they, moreover, lead up to the solution of those problems involving quantities of *latent heat*, touching which we are now going to speak. It must, however, be stated that the experiments that have enabled the determination of the calorific capacities of the different bodies

correspond only with a limited range of temperature, beyond which those capacities may be found to vary slightly. But, in practice, this uncertainty has no material importance, especially as bodies that are subjected to heat invariably lose, from accidental causes, quantities thereof considerably greater than could possibly arise from the incorrectness of the coefficients.

Latent Heat.—At the moment any change takes place in a body, whether it be its transition from the solid to the liquid state, or from this last to that of gas, a very curious and remarkable calorific phenomenon is observed. It is found that its temperature remains the same so long as the change in its state is going on, and consequently, that the quantities of heat with which it is supplied in the meanwhile are not perceptible by the thermometer.

This peculiarity is thus explained: while a body is changing its state, it absorbs a certain amount of heat which is exclusively employed in bringing about that change, but does not in any way tend to modify the temperature of the body. Hence the term *latent* given to that quantity of heat, which effectually is *hidden*, since it cannot be detected by the instrument generally used to reveal its presence. Latent heat was discovered, compared, and measured by Dr. Black.

In like manner, if either of the above-mentioned changes takes place inversely in a body—that is to say, if from the state of gas it passes to that of liquid, or from the state of liquid to that of solid—it will be observed to give out a certain quantity of heat without its temperature being in the least affected thereby while the operation is going on. This is nothing more than its abandonment of that *latent heat* which was necessary to maintain it in its recent state.

Fusion Heat.—The first example to be cited in demonstration of the existence of latent heat, is the transformation of water into ice, or, reciprocally, its return from the solid to the liquid state. Long before the experiments, which we will term *quantitative*, were made, it was known that there existed solid water (ice) as well as liquid water at zero, although it was necessary to heat the ice to cause it to melt. That already sufficed to reveal the existence of a certain amount of caloric absorbed solely by this change of condition; but its great importance had yet to be discovered. It was then shown, after very minute researches, that if 1 kilogramme of ice at zero be brought into contact with 1 kilogramme of water at 79°, there will remain, after the fusion is completed, 2 kilogrammes of water at the temperature of zero. Consequently, the whole of the manifest heat contained in the 1 kilogramme of liquid water is absorbed in reducing the 1 kilogramme of ice to a similar state; and, while the temperature of the latter remains unaltered, that of the former falls from 79 degrees to zero. The result would be the same if, instead of 1 kilogramme at 79°, we took 79 kilogrammes at 1°.

By referring to what has been said about calorific capacity, we perceive that the one kilogramme of water at 79° represented the same number of units of heat as were actually employed in melting the one kilogramme of ice; whence we conclude (see the experiments of MM. de la Provostaye and Desains) that

One kilogramme of ice, at the temperature of zero, will absorb 79 units of heat, called latent, or, more strictly, 79·25 units, in order to pass into the liquid state: that

One kilogramme of water, at no matter what temperature, contains, above zero, as many units of caloric as it does degrees of temperature, plus 79·25.

This phenomenon of latent fusion heat is common to all bodies which possess each their peculiar quantity of caloric absorbed for each unit of weight.

As, in steam-engines, water intervenes solely under its second change of state, we will not dwell any longer upon the first—though we deemed it indispensable that it should be known,—but will close this part of the subject by a few examples.

First example of the latent fusion heat of ice.—We propose to find the quantity of water necessary to melt a certain weight of ice at the assumed temperature of zero, which shall also be the temperature of the mixture after the fusion has taken place. Let the

Weight of the ice be	$W = 25$ kilogrammes.
Weight of the water be	$W' =$ unknown.
Temperature of the water be	$t = 15$ degrees.
Fusion heat be	$l = 79{\cdot}25$ units.

Solution.—On the one hand, it takes as many times 79·25 units as there are kilogrammes of ice; and on the other, that number of units is equal to the product of the weight of the water required by its temperature, that is to say, $W\,l = W'\,t$. Therefore we have

$$25 \times 79{\cdot}25 = W' \times 15^\circ;\ \text{whence } W' = \frac{25 \times 79{\cdot}25}{15} = 132{\cdot}08 \text{ kilos.}$$

Second example.—If $W = 10$ kilogrammes of ice at zero be thrown into $W' = 100$ kilogrammes of water at 18°, what will be the temperature x of the mixture after fusion?

Solution.—It will require 10 times l to melt the ice, which will have to be subtracted from the manifest quantities of heat contained in the water, or, 100 times 18 degrees; and the required temperature x is the quotient of that difference divided by the sum of the weights W and W'. Thus,

$$x = \frac{(t\,W') - (l\,W)}{W' + W} = \frac{(18^\circ \times 100) - (10 \times 79{\cdot}25)}{100 + 10} = 9{\cdot}16 \text{ degrees.}$$

We may here remark that it is easy to calculate the total amount of heat n that would be given out by this liquid mass in passing into the solid state at the temperature of zero. We should then have

$$n = (W + W')\,l + (W + W')\,x;\ \text{or, } (W + W') \times (l + x);$$

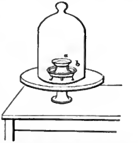
$$\text{whence}\quad n = (10 + 100) \times (79{\cdot}25 + 18^\circ) = 10697{\cdot}5 \text{ units.}$$

And, *vice versâ*, this same quantity of heat would be capable of increasing by one degree the temperature of 10697·5 kilogrammes of water.

Latent Heat of Steam.—During the second change of state to which bodies are liable, the effects are precisely identical with the above. When a liquid is transformed into steam it absorbs a very large amount of heat which is entirely undistinguishable by the thermometer, the steam having exactly the same temperature as the liquid whence it emanates. The difference that exists between the effects of fusion and evaporation is this, that, weight for weight, the quantities of latent heat absorbed are much more considerable in the latter case. But both possess this one peculiarity, that the absorption of latent heat takes place whatever may be the process of fusion or evaporation—whether slow or rapid. Thus, any vapour arising from simple ordinary evaporation in the open air possesses just the same quantity of latent heat as that arising from the ebullition of a body of liquid, subject to the same ambient pressure.

When steam is formed from a mass of liquid exposed to the action of a fire, it takes its latent heat from that liquid, which consequently ceases to increase in temperature. But, if this steam emanate from a liquid apart from any active source of heat, its latent heat is taken, not only from the liquid, but also from the vessel containing it and from the surrounding objects. There may thence result a very sensible cooling of those objects and of the said liquid, if the evaporation can be continued without recuperation of heat. Notwithstanding our desire to avoid purely physical disquisitions, we cannot refrain from citing an experiment that brings clearly to light this phenomenon of the absorption of latent heat by evaporation, no matter what the accompanying circumstances may be or the temperature at which it takes place.

844.



A cup of water, at the ordinary temperature, is made to stand over a saucer or pan containing concentrated sulphuric acid, and, the whole being placed under the receiver of an air-pump, as seen Fig. 844, we begin to exhaust the air. By degrees, as the vacuum is established and the pressure under the receiver diminishes, the water begins to boil, and evaporates the more rapidly as the action of the machine is accelerated. But the vapour thus formed, and which would soon arrest all further evaporation if allowed to remain under the receiver, is partly taken up by the machine while the remainder is absorbed by the sulphuric acid; consequently, the vacuum is maintained under the receiver and the evaporation continues. But, in a few moments, the water that remains in the cup will be completely congealed, forming one solid lump of ice.

This curious phenomenon is solely explained by the definition we have just expounded of latent heat. The steam, in forming, has borrowed so much caloric from the water as to lower the temperature of the latter to freezing point. It now remains for us to give the value of this latent heat of steam, whose outward effects are made visible by means of very simple experiments.

Amongst other experimentalists of merit, the learned M. Regnault made very minute researches touching the latent heat of steam, the general result of which will be found embodied in the following Table:—

TABLE OF THE QUANTITIES OF LATENT HEAT FOR STEAM FORMED BETWEEN 0° AND 230°.

Temperatures.	Latent Heats.	Temperatures.	Latent Heats.	Temperatures.	Latent Heats.	Temperatures.	Latent Heats.
0	607	60	565	120	522	180	479
10	600	70	558	130	515	190	472
20	593	80	551	140	508	200	464
30	586	90	544	150	501	210	457
40	579	100	537	160	494	220	449
50	572	110	529	170	486	230	442

The values that appear under the head of *latent heats* indicate the number of units of caloric absorbed by each kilogramme of steam, at the corresponding temperature, at the moment of its formation. Consequently, those same quantities of caloric would be given out by the steam on its return to the liquid state.

For a long time it had been admitted that the amount of latent heat was always the same, no matter at what temperature steam was generated; but the result of M. Regnault's researches shows that notion to be incorrect, and that the quantity of caloric that is absorbed by evaporation diminishes according to a certain progression which is in inverse ratio to the temperatures.

To select the most ordinary examples, let it be observed that whereas water at 100 degrees takes up 537 units of latent heat, that at 150 degrees only absorbs 501 units.

Application of the Latent Heat of Steam.—The general study of heat, in its reference to the formation of steam for mechanical purposes, is of twofold importance; firstly, as regards the quantities of fuel to be expended; secondly, as regards the condensation of that same steam after it has done its work. We will give examples of both cases.

First example.—What will be the total number a of units of caloric required by a weight $W = 25$ kilogrammes of water, whose temperature $t = 10$ degrees, in order to convert it into steam under the pressure of 1 atmosphere?

Solution.—The temperature T, apparent by the thermometer, of steam generated under a pressure of 1 atmosphere, being 100 degrees, the number of units of caloric absorbed by each

kilogramme of water will be $T - t$, plus the latent heat l that corresponds to the temperature t, according to the preceding Table. We therefore have for the total number of units

$$n = (T - t + l)\,W;$$

a general expression which gives for the proposed example

$$n = (100^\circ - 10^\circ + 537) \times 25 = 15675 \text{ units.}$$

Second example. Mixture of steam and water.—A certain quantity of steam being brought into contact with a given weight of cold water at a fixed temperature, and sufficient to complete its condensation, find the temperature of the mixture.

Let us take the same quantity of steam as in the foregoing example, added to $W' = 200$ kilogrammes of water, at a temperature $t = 15$ degrees; the steam being represented by $W = 25$ kilogrammes; $T = 100$ degrees; we want the temperature x of the mixture.

Solution.—The total mass, or the weight of the steam added to that of the water, will necessarily contain the sum of the quantities of heat possessed by each; if, then, we divide that sum by the entire mass, we shall have the temperature x demanded. Consequently

$$x = \frac{(T + l)\,W + (t\,W')}{W + W'}; \qquad [I]$$

which is a general expression, from which we obtain, as answer to our problem,

$$x = \frac{(100^\circ + 537) \times 25^k + (15^\circ \times 200^k)}{25^k + 200^k} = 84 \cdot 11 \text{ degrees.}$$

This result already shows that it is necessary, relatively, to use very considerable volumes of water to cause a body of steam to return to the liquid state, and in order that after the condensation the temperature of the water may not be too elevated.

Third example.—Let us reverse the proposition, that is to say, find what quantity of water must be added to a given weight of steam that the resulting mixture may not exceed a certain temperature.

Let W = 15 kilogrammes, the weight of the steam;
T = 150 degrees, its temperature;
l = 501, its latent heat (according to preceding Table);
W' = the weight of water required;
t = 10 degrees, its temperature;
t' = 25 degrees, the temperature of the mixture.

Solution.—By simply bearing in mind that t' takes the place of x, it is precisely the above formula [I], in which W' becomes the unknown quantity. Thus, $t'\,W + t'\,W' = (T + l)\,W + t\,W'$; whence

$$W' = \frac{(T + l - t')W}{t' - t}. \qquad [J]$$

This last expression is the one that we shall meet with every time that it is required to ascertain the condensation of a steam-engine; we therefore invite our readers to give it due consideration. As regards our present problem, it gives

$$W' = \frac{(100 + 501 - 25) \times 15}{25^\circ - 10^\circ} = 576 \text{ kilogrammes.}$$

That is to say, putting it in general terms, that in order that the condensation-water shall not exceed 25 degrees of temperature, it will take 576 kilogrammes of cold water at 10 degrees to destroy 25 kilogrammes of steam at 150 degrees. All things being equal, it is, moreover, evident that it will take so much more water to condense steam that the temperature of the water is higher and that of the mixture is required to be lower. It is beyond all doubt that, under certain circumstances, it is impossible to achieve the direct condensation of steam in engines and condensing machines for want of a sufficiently large volume of cold water. We shall see by-and-by that, in marine engines, the condensation is often imperfect or entirely suspended, not for want of water, since, in those cases, it is drawn from the sea, but because of the warmth of the water, especially under the tropics.

Here ends, for the present, what we had to say concerning latent heat; its direct application to engines will render sufficiently intelligible all that it is necessary to know upon the subject.

Sources of Heat. *Quantities of Heat supplied by Fuel.*—After the study of the *quantities of heat* required to raise the temperature of bodies and produce a change in their state, we come naturally to that of the *sources of heat* as regards the quantities that they are able to furnish. This forms the entire question of the economy of calorie in its production and its use.

Science teaches us that the combustion of a body is the chemical combination of that body with oxygen, a phenomenon which is accompanied by a great development of light and heat. If considered from this point of view, all bodies would be combustibles, since all possess, more or less, the property of combining with oxygen; but all do not offer, at the moment of entering into combination, such properties as qualify them for fuel, that is to say, a total disengagement of heat greater than that required to produce combustion, that combustion going on even independently of the focus where it takes place; and a cost price of the material itself sufficiently low. But, quitting generalities and basing our arguments upon a few examples, we will observe that wood, coal, hydrogen, and certain other substances burn almost spontaneously, or at least complete entirely their combustion from the moment that one single point of their mass has attained the necessary degree of temperature. Other bodies, such as metals, that combine freely with oxygen, cease burning as soon as they are withdrawn from the focus where the combination is effected; focus

which we are obliged, in consequence, to feed with some other body more readily combustible. Combustible bodies, that is to say, such as are used in manufacture, are not very numerous, and comprise:—

1. Woods, and vegetable matter generally;
2. Coals, both vegetable and mineral;
3. Peat.

These are the substances into whose composition there enters the greatest amount of carbon and hydrogen, the only two simple bodies which possess, independently, all the requisite properties for the phenomenon of combustion in its application to manufacture, and the quality, therefore, of being excellent combustibles. Animal substances, such as flesh, grease, and bone, are likewise highly combustible; but, on account of the complexity of their composition, the absorption of heat indispensable to the separation of their various elements at the moment of combustion is very considerable, so that a given weight of animal matter does not furnish so large an amount of useful heat as combustibles of a simpler nature. Besides this, there are sufficient uses for animal substances without employing them as fuel, though it has sometimes been done.

Our examination of combustibles can only be very brief, our object being merely to make known what quantities of heat each is able to furnish for every unity of weight.

The estimation of these quantities of heat is entirely based upon the calorific unity already defined. Thus let us suppose a kilogramme of any combustible body to be taken, and that it be found that the heat it has given out during its total combustion has raised the temperature of 2000 kilogrammes of water 1 degree; if the experiment be made with sufficient precision to satisfy us that all the heat thus produced has been absorbed by the water, we then say that the burning of 1 kilogramme of that combustible has supplied 2000 units of heat, for we are aware that that is the standard whereby we should measure the quantity of heat necessary to cause a variation of 1 degree in the temperature of 2000 kilogrammes of water. The amount of heat given out, so measured, takes the name of *calorific power* of the combustible whence it emanates; and very accurate experiments have been made in order to ascertain thus the calorific power of every substance. Those experiments have shown that not only does the said power differ with different bodies, but it also varies considerably in bodies whose composition is susceptible of change. Thus the combustibles used for industrial purposes, being substances of a complex nature, are all possessed of that peculiarity—a variable calorific power. For instance, woods, being of a kind, are essentially different in their composition, setting aside their greater or less degree of desiccation. The several sorts of coal, though variations in their composition are not so great, still show a difference. Even charcoal, one of the purest of all combustible substances, evinces likewise varieties, owing to its more or less perfect preparation.

Such differences should be considered, however, as of a scientific nature, not industrially: that is to say, every combustible possesses a mean calorific power which is all-sufficient for the purpose we propose. The following Table is a summary of the principal substances and their mean power, to which we have added the calorific powers of hydrogen and of bicarbonate of hydrogen or common gas, though these two last are not yet considered as combustibles in an industrial sense.

TABLE OF THE CALORIFIC POWERS OF COMBUSTIBLES USED FOR INDUSTRIAL PURPOSES.

Names of Combustibles.	Calorific Power expressed in units of Heat given out by the combustion of 1 kilogramme of each Substance.	Authorities.
Pure hydrogen (the kilo.)	34162	Favre and Silbermann.
„ (the cub. mèt.)	3067	„ „
Bicarburetted hydrogen (the kilo.)	11857	„ „
„ „ (the cub. mèt.) ..	15117	„ „
Pure carbon	8080	„ „
Charcoal (mean)	7000	Péclet.
Wood (very dry)	3700	Rumfort.
„ (ordinary condition) (mean)	2800	„
Coal (mean)	7000	Dulong.
Coke (to 0·15 of cinders)	6000	Péclet.
Common peat (mean)	3600	„
Purified colza oil	9307	Rumfort.
Alcohol, at 42° Beaumé	6855	Dulong.

The values indicated in this Table represent the maximum of heat for each corresponding combustible; we shall, therefore, term them the *theoretical calorific powers*, of which a certain amount only can be utilized in practice. See FUEL. It must not, however, be taken for granted that these values are entirely exempt from slight errors; the diversity of the results obtained by equally skilful experimentalists proves the contrary; and, besides, it is not probable that, in so complicated a phenomenon as that of the combustion of a body, the figures obtained can be always the same and invariable. But these differences become more manifest when the combustibles are employed for industrial purposes, and seem to banish all hope of our being able to rely on such calorific powers as mathematically correct, since, in these cases, they are neither prepared nor selected with the same care as when used for experiment only. These values, notwithstanding, such as they

are, may be of undeniable service, and this we shall see later. Besides, their degree of approximation is generally more than sufficient for all practical purposes. Fresh experiments, however, would perhaps be necessary and desirable, on account of certain new generators wherein the utilization of fuel appears to be increased in an extraordinary manner, as we shall have occasion to show hereafter.

The figure representing the calorific power of a combustible plays the same part in steam generators as does the measure of the expenditure of water in hydraulic motors; in both cases it is evidently the point upon which the result is based; therefore is it very important that there should exist no uncertainty regarding it.

Application of Calorific Power.—Before occupying ourselves with the sources of heat, we first examined the interchanges thereof that take place between different bodies, and then the amount of caloric requisite to increase the temperature of bodies a given quantity or cause their change of state. Having proceeded thus far, we are now prepared to calculate the amount of combustible necessary to be expended for the accomplishment of these operations.

We must, however, make one important remark, namely, that what we seek in the following examples is the *useful* quantities of heat, that is to say, those that are absolutely necessary, regardless of what is lost, and of the excellence of the focus or the disposition of the apparatus.

Researches respecting the Expenditure of Fuel required to produce a given Increase of Temperature.—First example.—What would be the useful quantity of charcoal necessary to increase the temperature of 100 kilogrammes of water 10 degrees?

Solution.—Since the preceding notions indicate in what manner we are to ascertain the quantity n of units of heat to be supplied, we very easily find that the weight w of the charcoal, whose calorific power we will call u, is $w = \frac{n}{u}$. Granting, according to the preceding Table, that $u = 7000$, the number corresponding to common charcoal, we then have

$$w = \frac{10 \times 100}{7000} = 0^{k}\cdot 142.$$

And that is, effectually, all the weight of coal that ought to be expended if the whole heat produced by the combustible could be absorbed by the water. But even supposing that the vessel that contains the liquid, and the focus, being previously heated, absorb none of the caloric, there would still remain other losses which would increase in a notable manner the above theoretical quantity. For instance, let us imagine the arrangements to be such that 0·6 of the heat are utilized, we should then burn, in reality, $\frac{0\cdot 142}{0\cdot 6} = 0^{k}\cdot 237$ of charcoal.

Second example.—What weight of coal must be burnt in order to liquefy 50 kilogrammes of ice at zero, and raise it to a temperature of 100 degrees?

Solution.—The number of units of heat n to be supplied being $(t + l)$ W, we have

$$w = \frac{(100 + 79) \times 50}{7600} = 1^{k}\cdot 177 \text{ of coal.}$$

Evaporating Power of a given Weight of Combustible.—What weight of steam at a temperature of 100 degrees would be produced by the useful expenditure of 1 kilogramme of coal, supposing the temperature of the water, before heating, to be 15 degrees?

This is the most important problem of the application of caloric to steam-engines; it is the pivot, as we shall presently see, around which all the improvements therein that have hitherto been conceived, and are still likely to be, revolve.

Solution.—It has already been seen [H] that the number of units of heat necessary to a certain weight of water, in order to convert it into steam, is expressed by $n = (T - t + l)$ W; and as that number of units must be equal to the number given out by the weight w of the proposed fuel, whose calorific power is u, we have $wu = (T - t + l)$ W; hence the required weight of steam will be $W = \frac{wu}{T - t + l} = \frac{1^{k} \times 7600}{100 - 15 + 537} = 12^{k}\cdot 21$; which amounts to this, that

1 kilogramme of coal can, THEORETICALLY, *evaporate about 12 kilogrammes of water, whose temperature, before the application of heat, was 15 degrees.*

If we had supposed the steam to be of a higher temperature, the quantity of fuel would likewise have been slightly increased, but only slightly, because the latent heat, which is more considerable, varies but little, and inversely. We will give no further example, as this last will suffice as the basis for all future discussions upon the subject. It is essential, however, that we should make one remark with regard to the above result as compared with those obtained in practice.

Generally speaking, a good generator will evaporate 7 kilogrammes of water; very often it is less; but sometimes it is more, and even, in certain cases, it has almost touched the theoretical figure of 12 kilogrammes, which it seems very difficult to attain, if ever. By the aid of special arrangements, however, and such artifices, for instance, as activating the combustion by means of an additional current of air, and so completing the conversion of the coal into carbonic acid and preventing any particle of matter escaping without being consumed and giving up its contribution of heat, it may be done. This is what is called *consuming the smoke*, which is nothing else, for the most part, but unconsumed, and consequently non-utilized coal. It may be well to remind our readers that the number 7600, which indicates in the preceding Table the number of units of heat for every kilogramme of coal, is a *mean*, and may, consequently, be sometimes exceeded. To establish absolute limits, we will suppose that pure carbon is used, furnishing 8000 units of heat, and we then find that 1 kilogramme of that superior fuel, compared with coal, yet only supplies

$$\frac{12\cdot 21 \times 8000}{7600} = 12^{k}\cdot 84 \text{ of steam.}$$

We have given no examples of the use of the other combustibles, since in all cases the operation would be evidently identical; it is simply necessary to alter the value of u, that is, of the coefficient of calorific power. The only point that it might be interesting to examine is the cost of the unit of heat with each different combustible, and this has been done with much care by Péclet in his excellent 'Treatise on Heat.' But it is to be remarked that the use of such or such a combustible depends much less upon its venal value than upon the greater or less facility with which it can be procured in each locality. Thus, some countries possessing coal and comparatively little wood, like England, France, and Belgium, usually adopt the first as fuel, it being also the one that gives out the most heat as it occupies the least space, and is capable of producing a more intense increase of temperature at the focus. On the other hand, there are services, such as the navy, which will always choose the richest combustible because of the economy of space. But it also sometimes happens that a manufacturing establishment possesses some fuel emanating from its own works, and therefore at its disposal almost free of cost, on which account it uses it without having to inquire whether it is more or less rich than this or that other. Thus it is that we see saw-mills feeding their furnaces with sawdust and shavings, tan-yards using their tan, and the sugar-refiners of the colonies the peelings of the dried canes. So that the cost of the unit of heat could only have a real interest in such an event as all the combustibles being equally accessible, a circumstance which, we may safely say, never takes place.

MECHANICAL PROPERTIES OF STEAM. *Conditions relating to the Flow and Expenditure of Steam.*—All that has hitherto been seen regarding steam may be considered as constituting its physical properties, that is to say, those natural phenomena, occasioned by the intervention of heat, which convert a body into a gaseous fluid that may be considered as such, and possessing all the characteristics of permanent gases. Like unto the latter, and fluids in general, steam is susceptible of motions and effects that no longer arise from the mutual actions of the ponderable or imponderable elements of which it is formed, but from the *mechanical efforts* to which it may be subjected or which it is capable itself of producing.

If we adopt water as our standard of comparison, we observe that this liquid, independently of its physical properties, such as density, calorific capacity, and so forth, possesses also the mechanical properties due to the action of gravity, which enable it to be considered under the aspect of its motions, the velocity it can acquire, and the efforts it is able to transmit by yielding to the influence of gravitation and of its own substance. The same thing precisely happens with steam, and gases in general, which can move, acquire velocity, and, finally, exert mechanical efforts by virtue of their expansive force, which here takes the place of simple gravity in a liquid.

We propose, therefore, to examine steam under these several phases, giving to our investigations the title of *pneumodynamics*.

Flow of Steam through a Narrow-edged Orifice.—When two vessels, containing gases of unequal pressures, are made to communicate, a flow of gas immediately takes place from the vessel where the pressure is the greatest to that where it is the least; precisely as it would occur if, instead of gases, the two vessels held liquids of different densities or uneven levels, or if one of them were entirely empty.

Gases, like liquids, tend towards establishing their equilibrium, then, and in so doing, both follow the same law.

It is shown that the flowing of a fluid through an orifice bored in the side of the vase containing it, and below the free surface, depends, as regards velocity and product, upon two principal conditions—the section of the orifice and the vertical distance between its centre and the surface of the liquid; and that the velocity is expressed by the invariable formula $v = \sqrt{2gh}$ (see HYDRAULICS), where g equals 9·8088, and represents the velocity acquired in one second of time by a body falling in vacuum.

It is also shown that the volume of water flowing, in a given time, is the product of that velocity by the section of the orifice, and by a certain coefficient of contraction.

It is exactly the same with gases, only that the height h of the liquid is replaced by the expansive force of the gas. Consequently, setting aside for the present the other conditions of the problem, let us see what the value of h would be in the case of a gas. For this purpose we will suppose that the flow takes place through a narrow-edged orifice which, by its contraction, diminishes the expenditure, but without altering the velocity.

845.

Velocity with which a Gas flows from a Narrow-edged Orifice.—Theory and experiment both prove *that the velocity of an* ELASTIC *fluid, flowing in a certain medium and through a narrow-edged orifice, is the same as that which, under similar conditions, would be possessed by a* NON-ELASTIC *fluid of equal density with the gas, but which, by its height of column above the centre of the orifice, would be capable of exerting a relatively equal pressure.*

To render this theorem fully intelligible, let us suppose two vases, A and B, Fig. 845, both standing in the same medium, the atmosphere for instance, the one being filled with a liquid and the other with a gas, under the following conditions:—1st, the gas in the vase A to have a certain pressure; 2nd, the liquid in the vase B *to be of the same density as the gas*, unconfined, and having a height of column h sufficient to press the bottom of the vessel B with an intensity equal to the pressure exerted by the gas against the inner sides of the vessel A.

These conditions being satisfied, if a small orifice a be opened at some point of the vase A, and another b at the lower part of the vase B, the gas and the liquid will both begin to flow, and with the same velocity. This law enables us to work out a first problem which will assist us in establishing the general formula applicable to our present requirements.

Let it be proposed to ascertain with what velocity a second atmospheric air, at a temperature of 0 degrees, would re-enter a perfect vacuum; we have

Pressure of air (in cent. of mercury)	$P = \overset{m.}{0 \cdot 76}$
Density „	$d = 0 \cdot 001299$
„ of mercury	$d' = 13 \cdot 598$
Pressure of medium where the flow takes place	$p = 0 \cdot 0$
Velocity of flow in a second of time	$e = \sqrt{2gh}.$

It will be seen, in accordance with the preceding theorem, that there only remains to ascertain h to complete the solution of the problem. Moreover, we know that that height must be equivalent to a column of liquid of the same density as air, and exerting the same pressure at its base, that pressure being equal to the difference of pressures between the gas and the medium where the flow takes place, or $P - p$. But here p being a vacuum, and consequently equivalent to zero, the pressure $P - p$ is exactly equal to P, and corresponds with a column of mercury of $0^m \cdot 76$; the height of the column of non-elastic fluid that would balance it is, therefore, in the inverse ratio of the densities of the fluid and the mercury; that is to say,

$$h = P\frac{d'}{d} = 0^m \cdot 76 \times \frac{13 \cdot 598}{0 \cdot 001299} = 7955 \cdot 7 \text{ mètres.}$$

It would therefore take a column of fluid 7955·7 mètres in height, and of the same density as the air, to balance a column of $0^m \cdot 76$ of mercury. Consequently, the velocity due to such a height will be $v = \sqrt{19 \cdot 62 \times 7955 \cdot 7} = 395$ mètres, the answer sought, or the velocity with which atmospheric air, at a temperature of 0 degrees, would re-enter an exhausted vessel.

In cases where there is no occasion to keep account of the changes in volume and density caused by temperature, this problem offers no difficulty; and it is in this sense that we shall find the means of applying it to steam, of which the Tables at page 416 give the pressure and density in relation with the temperature, which, consequently, may be omitted from the foregoing calculation.

The general formula for finding the velocity of a gas or steam is therefore the following:

$$v = \sqrt{2g(P - p)\frac{d'}{d}};$$

wherein v represents the required velocity in a second of time;
g „ the intensity of gravitation, equal to 9·8088;
P „ the absolute pressure of the gas or steam, in mètres of mercury;
p „ the pressure of the medium where the flow takes place, expressed in the same units.
d' „ the density of mercury compared with that of water and equal to 13·598;
d „ the density of the flowing gas, also compared with that of water.

By introducing the fixed quantities into the preceding general formula, we first of all get the following expression:

$$v = \sqrt{\frac{2 \times 9 \cdot 8088 \times (P - p) \times 13 \cdot 598}{d}};$$

which may be simplified by obtaining the product of these same quantities, till it finally becomes

$$v = \sqrt{\frac{266 \cdot 76\,(P - p)}{d}}.$$

If the pressure $P - p$ were expressed in atmospheres and fractions of atmospheres, it would be necessary, in order to get the real initial height in mètres of mercury, to multiply it by the height of mercury that balances one atmosphere.

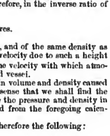
Thus modified, the formula would be

$$v = \sqrt{\frac{2 \times 9 \cdot 8088 \times 0 \cdot 76(P - p)13 \cdot 598}{d}};$$

by simplifying as before, we get

$$e = \sqrt{\frac{202 \cdot 7376\,(P - p)}{d}}.$$

846.



The resultant pressure $P - p$, constituting the initial height of the effective velocity of the flow, may be derived from direct observation, according to the disposition of the instrument used in ascertaining it. That instrument would be the *Air Manometre*, or differential indicator of pressure, which may be used to measure the elastic force of a gas or steam in relation to a certain ambient medium.

Let us suppose a vessel A, Fig. 846, to enclose some aëriform fluid, at a higher pressure than that of the medium in which it is placed. If we attach to it a tube B containing mercury, bent in the shape of the letter U, with its shorter branch communicating with the interior of the vessel, while its longer one is left open at the top, the internal pressure, acting upon the mercury, will cause it to rise in the open branch. To find the conditions of equilibrium of the mercury, when it is thus displaced, it will be sufficient to draw a horizontal line S L through the summit of the lower column, and then examine the nature of the pressure to which the mercury is subjected at every

point of that line. In the longer branch it is equal to the pressure of the ambient medium, plus the height h to which the mercury has been raised in the tube; and as it must be the same in the shorter branch, and is due entirely to the pressure in the reservoir A, we conclude that that pressure is equal to the external pressure, plus the height h of the mercury. Consequently, that height is precisely equal to the difference of the two pressures, and is none other than $P - p$, which figures in the preceding calculation.

For the future, therefore, every initial pressure of the velocity of a flow will be represented in our operations by a column h of mercury, observed in strict accordance with the foregoing method. It is that pressure which, estimated in mètres, must be multiplied by the ratio of the density of the mercury to that of the fluid under consideration, in order to obtain the real height which becomes the initial of the velocity with which the fluid flows.

Problems relating to the Flow of Steam through Narrow-edged Orifices.—Let us propose to find the velocity with which steam would flow in a medium of determinate pressure.

First example.—Find the velocity with which steam would flow through a narrow-edged orifice into the open air under a pressure of 3 atmospheres.

Solution.—Steam, under a pressure of 3 atmospheres, is represented by a column of mercury of $P = 0{\cdot}76 \times 3 = 2^{m}{\cdot}28$; and the Table at page 405 indicates that its density is $d = 0{\cdot}001615$. On the other hand, if the pressure of the ambient medium is $0{\cdot}76$, the required velocity will be

$$v = \sqrt{\frac{266{\cdot}76 \times (2{\cdot}28 - 0{\cdot}76)}{0{\cdot}001615}} = 502 \text{ mètres.}$$

Second example.—Find the velocity with which steam flows at a pressure of 5 atmospheres, difference of pressure between the reservoir and the medium in which the flow takes place being measured by a column of mercury $= 0^{m}{\cdot}45$.

Solution.—We have $P - p = 0{\cdot}45$; and $d' = 0{\cdot}0025763$, according to the same Table; whence

$$v = \sqrt{\frac{266{\cdot}76 \times 0{\cdot}45}{0{\cdot}0025763}} = 216 \text{ mètres.}$$

Third example.—Find the velocity of steam under a pressure of $3{\cdot}75$ atmospheres, the pressure of the medium in which it flows being $1{\cdot}80$ atmosphere.

Solution.—By the same Table to which we have referred in the two preceding examples, we find that the density of steam at $3{\cdot}5$ and 4 atmospheres is $0{\cdot}0018589$ and $0{\cdot}0020997$ respectively; therefore, the density of steam at $3{\cdot}75$ must apparently be a mean between these two numbers; that is,

$$d' = \frac{0{\cdot}0018589 + 0{\cdot}0020997}{2} = 0{\cdot}0019793.$$

The pressure expressed in atmospheres, will this time be

$$P - p = 3{\cdot}75 - 1{\cdot}80 = 1{\cdot}95.$$

Consequently, by a suitable adaptation of the foregoing formula, we have

$$v = \sqrt{\frac{202{\cdot}7376 \times 1{\cdot}95}{0{\cdot}0019793}} = 447 \text{ mètres.}$$

The above examples being sufficient to illustrate the application of the rule, we will not add any more; but merely make a few remarks called forth by the rule itself.

The arrangement of the formula shows the general mode in which gases flow, and further points out that,

1st. *The velocities are proportional to the square roots of the effective pressures;* that is to say, to the excess of pressure that causes the flow;

2nd. *They are inversely as the square roots of the densities.*

From which we conclude, in addition, that when a gas is compressed whose density is proportional to the pressure it bears, with an even temperature, the velocities are always equal, whatever may be the degree of compression.

With regard to steam having a maximum of elasticity whose density is not proportional to the expansion, there exists, however, a limit where the velocity of the flow ceases to increase with the pressure.

For instance, let us suppose two currents of steam flowing into the atmosphere, the one with an expansive force of 5 atmospheres, the other of 10, and whose densities, according to the Table, page 405, are $0{\cdot}0025763$, and $0{\cdot}0048226$ respectively, and endeavour to find their corresponding velocities. We have,

$$\text{For 5 atmospheres,} \quad v = \sqrt{\frac{202{\cdot}7376 \times (5 - 1)}{0{\cdot}0025763}} = 562 \text{ mètres;}$$

$$\text{For 10 atmospheres,} \quad v = \sqrt{\frac{202{\cdot}7376 \times (10 - 1)}{0{\cdot}0048226}} = 615 \text{ mètres.}$$

That is, a difference of only 53 mètres in velocity for a difference of expansion of 5 atmospheres.

Tables and Graphic Tracing in Reference to the Flow of Steam.—The solution of such problems as those we have just been examining always requires a special aptitude, and too much time for ordinary practitioners, as a rule, to turn them to their fullest account; moreover, there are interests of another order involved, and not less important, that render it imperative not to trust to the uncertain results of direct calculation: a manufacturer, on the contrary, needs reliable information, such as can alone emanate from the labours of the man of science, in the quiet seclusion of

his own study, and away from every other preoccupation. That is why tables are of such undeniable utility, by enabling the solution of a proposed question promptly and with certitude: for the figures we borrow from them form part of a series in regular progression, whose terms verify one another, so to speak, by their simple connection. Therefore we have always endeavoured, as much as possible, to make them accompany the practical rules, in order to simplify calculations and ensure correct results.

It is with this view that we produce the two following Tables of the velocity of steam under the circumstances most generally met with in practice. These two Tables, which may be readily made by means of the foregoing rules, are taken from that excellent work, 'The Locomotive Driver's Guide,' by MM. Flachat and Petiet. The first relates to the flowing of steam in the open air, under pressures varying from 5 to 1·01 atmospheres; together with its density, or weight of a cubic mètre for each pressure. The second Table gives the velocity of steam under pressures of 5, 4, and 3 atmospheres, in media whose pressures vary from 4·95 to 1·25 atmospheres, while one column is reserved for the effective pressure exerted by the steam upon every square mètre of surface. This pressure is evidently the same in the three cases where the resisting pressure is the same, since the differences also are identical. Consequently, these two Tables complete the series. Afterwards we shall give a graphic tracing, whereby the same problems may likewise be solved. In all cases the flow is supposed to take place from a narrow-edged orifice; for, were its thickness considerable, and comparable to the development of a tube, the velocity would be altered. We shall have occasion to allude to this view of the subject presently.

TABLE I.—THE VELOCITY WITH WHICH STEAM ESCAPES INTO THE ATMOSPHERE UNDER DIFFERENT PRESSURES.

Absolute Pressure of the Steam.	Weight of a Cubic Mètre.	Velocity in a Second.	Absolute Pressure of the Steam.	Weight of a Cubic Mètre.	Velocity in a Second.	Absolute Pressure of the Steam.	Weight of a Cubic Mètre.	Velocity in a Second.
5·00	2·568	562	1·75	0·984	394	1·12	0·674	194
4·75	2·457	551	1·60	0·900	368	1·10	0·636	178
4·50	2·334	549	1·50	0·854	343	1·09	0·630	170
4·25	2·217	546	1·45	0·830	331	1·08	0·626	161
4·00	2·096	537	1·40	0·800	318	1·07	0·622	151
3·75	1·972	530	1·35	0·778	302	1·06	0·619	140
3·50	1·855	520	1·30	0·750	285	1·05	0·610	129
3·25	1·734	512	1·25	0·722	265	1·04	0·607	116
3·00	1·611	502	1·22	0·705	252	1·03	0·601	101
2·75	1·487	488	1·20	0·698	242	1·02	0·598	83
2·50	1·363	472	1·18	0·681	232	1·01	0·595	58
2·25	1·238	451	1·16	0·670	220	1·00	0·590	0
2·00	1·111	427	1·14	0·658	213	..	..	..

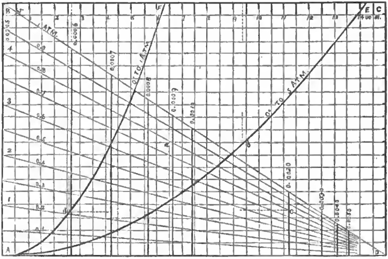
TABLE II.—THE VELOCITY WITH WHICH STEAM ESCAPES INTO MEDIA OF DIFFERENT PRESSURES.

STEAM AT 5 ATMOSPHERES ABSOLUTE.			STEAM AT 4 ATMOSPHERES ABSOLUTE.			STEAM AT 3 ATMOSPHERES ABSOLUTE.		
Pressure in the Receiver.	Effective Pressure in kilos. on every Square Mètre.	Velocity in Mètres in one Second.	Pressure in the Receiver.	Effective Pressure in kilos. on every Square Mètre.	Velocity in Mètres in one Second.	Pressure in the Receiver.	Effective Pressure in kilos. on every Square Mètre.	Velocity in Mètres in one Second.
4·95	517	63	3·95	517	69	2·95	517	79
4·90	1·034	89	3·90	1·034	97	2·90	1·034	112
4·85	1·550	108	3·85	1·550	120	2·85	1·550	137
4·80	2·067	125	3·80	2·067	139	2·80	2·067	158
4·75	2·584	140	3·75	2·584	155	2·75	2·584	178
4·65	3·618	166	3·65	3·618	184	2·65	3·618	210
4·55	4·651	188	3·55	4·651	209	2·55	4·651	238
4·50	5·168	198	3·50	5·168	220	2·50	5·168	251
4·25	7·752	242	3·25	7·752	269	2·25	7·752	307
4·00	10·336	281	3·00	10·336	311	2·00	10·336	355
3·75	12·920	314	2·75	12·920	347	1·75	12·920	396
3·50	15·504	344	2·50	15·504	380	1·50	15·504	423
3·25	18·088	371	2·25	18·088	411	1·25	18·088	469
3·00	20·672	396	2·00	20·672	439	..	..	..
2·75	23·256	421	1·75	23·256	466	..	..	..
2·50	25·840	444	1·50	25·840	491	..	..	..
2·25	28·424	465	1·25	28·424	515	..	..	..

Graphic Tracing.—The method of tracing which we are now going to explain, and whereby the velocities of gases through narrow-edged orifices may be ascertained, is due to Robert Bishop Hennessey, and is analogous to that given in their 'Treatise on Hydraulic Motors,' for the purpose of estimating the expenditure of water through orifices with a load upon the centre.

This one, Fig. 847, is so arranged as to give the maximum velocity of gases having densities, compared with that of water, which vary from 0·0005 to 0·005, and relative pressures from 0 to 5 atmospheres. A series of right lines, starting from the point D, corresponds, for the curve A E,

847.



to pressures varying from 1 to 5 atmospheres, and, for the curve A F, from 0·1 to 1 atmosphere. Another series of vertical lines, including A B, represents the densities from 0·0005 to 0·005. The upper scale B C expresses the velocities in large divisions of 100 mètres.

Use of the Tracing.—Find the intersection of the vertical, indicating the density, with the oblique, corresponding to the relative pressure P − *p*, and, from the point of intersection, follow the horizontal line till it meets the curve; from this second point draw a vertical line which project till it reaches the scale B C, and you have the velocity required. For instance, we want the velocity of a gas whose density is 0·0009, and whose relative pressure is 4 atmospheres. We look for the intersection *a* of the vertical line 0·0009 with the oblique line 4 D, and from that intersection we follow the horizontal line till it meets the curve A E at *b*; then, by raising a vertical line from this last point to the scale B C, we then obtain an approximate reading of 940 mètres, which is the velocity sought. By strict calculation it would be 943 mètres.

To give an example of the use of the second curve, let us try to find the velocity of a gas whose density is 0·002, with a relative pressure of 0·7 atmosphere. The process is exactly the same. The intersection *c*, of the oblique 0·7 D, with the vertical corresponding to the number 0·002, gives the horizontal dotted line *c d*, which cuts the curve A F at *d*; by producing a vertical from this point on to the scale above, as before, we find about 265 mètres as the required velocity. Mathematically it would be 266 mètres.

These slight differences between the quantities found by calculation and those obtained by means of the diagram do not arise from any want of accuracy of principle in the latter, but solely from difficulties of execution, it being impossible to complete the subdivision of the scales; but by enlarging the tracing, this obstacle may be lessened or removed, and the result becomes proportionately more correct.

It would be precisely the same thing for any value not indicated in this diagram; all that is required is to suppose the line A B, as base, divided into quantities proportional to every intermediate pressure between 0 and 5 atmospheres, with oblique lines running from the several points to the point D. As regards the series of verticals of density, the same principle may be carried out, by imagining intervening lines at distances inverse to their values, for such densities as are not comprised in the diagram.

Velocity of Gas flowing through a Pipe.—Hitherto we have only considered the velocity of gas flowing through a narrow-edged orifice, where the friction is, consequently, insufficient to produce any noticeable effect; but when a gas passes through a pipe of a certain length, the case is very different. Then its velocity, as it leaves the pipe, is less than that which would be due to the initial pressure in the reservoir, or to its excess of pressure P − *p* over that of the medium into which it flows. There must have been, therefore, a loss of force occasioned by the resistance of the pipe to the motion of the gas. The learned D'Aubuisson found that resistance subject to the following laws:—

1st. The resistance is proportional to the length of pipe;
2nd. It increases with the square of the velocity;
3rd. It is in the inverse ratio of the diameter.

Let us, consequently, call

P, the pressure within the reservoir, or its excess h over that of the medium where the flow takes place, expressed in mètres of mercury;
p, the initial height of the effective velocity with which the gas escapes at the end of the pipe; that height likewise expressed in mètres of mercury;
v, the effective velocity;
L, the length of the pipe in mètres;
D, its diameter, also in mètres;
D', its diameter at the extremity, or that of the aperture whence the flow takes place, the pipe being supposed to terminate with a conical converging ajutage;
k, an experimental coefficient.

We then have, according to D'Auhuisson, the following relations:

The mean velocity u of the flow throughout the whole length of the pipe will be evidently equal to its effective velocity v on leaving the ajutage, multiplied by the inverse ratio of the squares of the diameters D and D', that is to say, $u = v \times \frac{D'^2}{D^2}$; and $u^2 = v^2 \times \frac{D'^4}{D^4}$.

But the velocity v is represented by $v = \sqrt{2gp}$, whence $v^2 = 2gp$, and $p = \frac{v^2}{2g}$, p being, as we have said, the initial height h of the velocity with which the gas escapes from the pipe. On the other hand, considering that the force absorbed by the resistance of the pipe has resulted in the reduction of the pressure from P to little p, that force will be expressed by $P - p$; so that, from what precedes, we get the following equation: $P - p = k\frac{L u^2}{D}$. But the foregoing relations give $p = \frac{v^2}{2g}$, and $u^2 = \frac{v^2 D'^4}{D^4}$; substituting, therefore, these values for p and u^2, we obtain $P - \frac{v^2}{2g} - k\frac{L v^2 D'^4}{D^5}$, whence, extracting at once the value of v, we get

$$v = \sqrt{\frac{2gPD^5}{k2gLD'^4 + D^5}}. \qquad [K]$$

This value, therefore, is that of the real velocity with which the gas escapes (setting aside its density for the moment), after traversing the whole length of the pipe, and issuing from a contracted orifice of the diameter D'.

If the contracted orifice of the ajutage were equal in diameter to the pipe, we should have $D' = D$, and the formula would be modified as follows:

$$v = \sqrt{\frac{2gPD}{k2gL + D}}. \qquad [L]$$

As to the value of the coefficient k, it is deduced from D'Auhuisson's experiments, who ascertained that of an experimental number n, whose mean was $0 \cdot 0238$, in which $2g$ enters as factor. Consequently, by performing the division we have $\frac{0 \cdot 0238}{19 \cdot 62} = 0 \cdot 0012$, which number becomes the value of the coefficient k. It is evident that this result is very liable to change according to the nature or state of the surface over which the gas has to pass. D'Auhuisson obtained it by making atmospheric air pass through tin tubes, which must have offered but little resistance compared with cast-iron pipes, whose surfaces are usually rough. It becomes then a matter of option either to adopt this value in the above equations, or else to substitute in the denominator the constant number $0 \cdot 0238$ for the factor $k2g$, whereby the final values will be in no way changed.

To end this subject and give a few examples, we will now complete the formulas by applying the multiplier relative to the densities. The velocities represented by those formulas, such as we have defined them, are those that would correspond to heights of manometrical pressure; that is to say, expressed by columns of mercury. In order to obtain the velocities of gases having the corresponding pressures, it is sufficient to multiply, as before, the two terms beneath the radical by the ratio of the densities of the mercury and the gas under consideration. By again representing the density of the mercury by d' and that of the gas by d, we have

$$v = \sqrt{\frac{2gPD^5}{k2gLD'^4 + D^5}\,\frac{d'}{d}} = \sqrt{\frac{266 \cdot 76\,PD^5}{(0 \cdot 0238\,LD'^4 + D^5)d}} \qquad [M]$$

for the first formula [K], where the diameter of the orifice from which the gas flows is supposed to be different from that of the pipe. And for the second formula [L], where the diameters are equal,

$$v = \sqrt{\frac{266 \cdot 76\,PD}{(0 \cdot 0238\,L + D)\,d}}. \qquad [N]$$

It may be useful, however, to observe that, in the latter case, the coefficient ought perhaps to be modified, since it was obtained by means of pipes with a contracted end. But the error committed by leaving it as it is would be of very little importance, considering that in practice the departure from theoretical results is generally far greater.

Problems relating to the Passage of a Gas through a Pipe.—Let us endeavour successively to find with what velocity both air and steam would flow, under the two separate conditions:—1st, where the pipe is terminated by a conical *ajutage*, diminishing the diameter where the gases escape; 2nd, where the diameter is the same throughout.

First example.—Find the velocity with which air flows through a pipe having an ajutage, with the following data:—

Pressure or height h at the commencement of the pipe ..	$P = 0·10$ mètres.
Length of pipe	$L = 60$,,
Diameter of pipe	$D = 0·20$,,
Diameter of orifice where it escapes	$D' = 0·05$,,
Supposed density of the air (according to its temperature)	$d = 0·0013$,,

Solution. Formula [M].—Admitting that the state of the pipe admits of the application of the coefficient given by D'Aubuisson, we find

$$v = \sqrt{\frac{266·76 \times 0·10 \times \overline{0·20}^5}{\left(0·0238 \times 60 \times \overline{0·05}^4 + \overline{0·20}^5\right) \times 0·0013}} = 140·9 \text{ mètres.}$$

If the velocity were not affected by friction with the pipe, it would be the same as that due directly to the pressure 0·10, according to the foregoing rules, and equal to 144 mètres. There is, then, a loss of rather more than 3 mètres, which is very little. But that is because we have supposed the orifice where the gas escapes to be much smaller in diameter than the pipe, whereby the velocity is lessened in proportion. For, the diameters being respectively 20 and 5 centimètres, the mean velocity u within the pipe will only be $\frac{1}{16}$th (square of the ratio of the diameters) what it is on leaving it, barring a correction on account of the contraction of the orifice, and whose coefficient is equal to about 0·93; let

$$u = \frac{v\,\overline{D'\,0·93}^2}{D^2} = \frac{140·9 \times 0·0025 \times 0·8649}{0·04} = 7·61 \text{ mètres.}$$

So that the loss due to friction is extremely small.

Second example.—Find the velocity of the flow under the same conditions as above, with the exception that the pipe is supposed to be completely open at the end; so that we have $D' = D$.

Solution.—By adapting the formula [N] to suit the case, we have

$$u = \sqrt{\frac{266·76 \times 0·10 \times 0·20}{(0·0238 \times 60 + 0·20) \times 0·0013}} = 50·4 \text{ mètres.}$$

It will be perceived, in this instance, that the velocity is notably altered; but it must also be observed that that has been its mean velocity throughout its entire course.

Third example.—Find with what velocity steam would be discharged through a pipe into the ambient air, with a pressure of 4 atmospheres, under the following conditions:

Effective pressure of the steam (3 atmospheres), or ..	$P = 2·28$ mètres.
Density	$d = 0·0021$,,
Length of pipe	$L = 25$,,
Uniform diameter of pipe	$D = 0·12$,,

Solution. Formula [N].—The mean velocity within the pipe, as well as that with which the steam escapes, are apparently equal to

$$v = \sqrt{\frac{266·76 \times 2·28 \times 0·12}{(0·0238 \times 25 + 0·12) \times 0·0021}} = 220·6 \text{ mètres.}$$

Had the velocity not been altered, we should have had

$$u = \sqrt{\frac{266·76 \times 2·28}{0·0021}} = 538 \text{ mètres.}$$

The change in the velocity is, therefore, very considerable; but, as the velocity is also great, the result is simply in conformity with the theory according to which the force absorbed by friction increases as the square of the velocity.

Fourth example.—Let us take the same data as before, but with a diameter of pipe of 20 centimètres instead of 12, so as to see what effect it will have.

Solution.—Using the same formula, we have

$$u = \sqrt{\frac{266·76 \times 2·28 \times 0·20}{(0·0238 \times 25 + 0·20) \times 0·0021}} = 268 \text{ mètres,}$$

in lieu of $220^m·6$ with a pipe $0^m·12$ in diameter, and about half the maximum velocity 538 due to the relative pressure of the steam if no friction existed.

Volumes of Steam that are discharged through simple Orifices and Pipes.—It is clear that the only difficulty in the way of solving the question of the expenditure of gases and steam, was the ascertaining its velocity. As to the volumes discharged, they are, as in the case of incompressible fluids, the product of that velocity by the section of the orifice, and by a coefficient of contraction determined by experiment. Consequently, the latter part of the problem may be considered simply as a remark, having reference principally to the coefficient of contraction that ought to be adopted.

Coefficients of Contraction.—D'Aubuisson found that, as in the case of incompressible fluids, the coefficients of contraction m applicable to the expenditure of gases had the following values:

For a narrow-edged orifice	0·65
For a short cylindrical ajutage	0·93
For a short ajutage, but slightly tapering ..	0·95

To obtain the real expenditure it suffices, therefore, to multiply the theoretical product by one of the above values, according to the nature of the case.

First example.—A certain gas flows through a narrow-edged orifice 5 centimètres in diameter, with a velocity equal to 150 mètres a second; find the total volume Q discharged in a minute.

Solution.—We find $Q = \dfrac{\overline{0\cdot05}^2 \times \pi \times 150 \times 60 \times 0\cdot65}{4} = 11\cdot486$ cubic mètres.

Second example.—The orifice of the supply-pipe being rectangular and measuring 20 centimètres by 3, and open in full during a reduced time of 0·5 of a second, what volume of steam would enter the cylinder of an engine, supposing the pressure and density to correspond to a velocity equal to 300 mètres?

Solution.—We have $0\cdot03 \times 0\cdot20 = 0^{\mathrm{sm}}\cdot006$ for the surface of the orifice. If we take 0·9 as the coefficient, then $Q = 0\cdot006 \times 300^{\mathrm{m}} \times 0\cdot5 \times 0\cdot9 = 0\cdot810$ cubic mètres.

As regards the expenditure through a pipe, we may observe that, in the case of a narrow ajutage, the coefficient 0·93 may be used; but it is to be dispensed with when the pipe is cylindrical. The operation is reduced, therefore, to precisely the same terms as before.

Note relating to the finding the Diameter of a Pipe where the Flow is to take place under certain Fixed Conditions.—Generally speaking it is not a difficult problem to ascertain what ought to be the dimensions of an orifice in order to satisfy certain definite conditions; but it is not the same as regards the dimensions of a pipe, whose diameter, we have seen, enters as two different powers in the expression of the velocity and the expenditure. It is possible, however, to arrive at a practical result of sufficient accuracy by the aid of a simple method of which we will endeavour to lay down the elements. Of course we suppose the pipe to be uniform in diameter and without contraction. If we bring together the expression of the velocity and that which corresponds to the section of the pipe—which we have supposed all along to be circular—and multiply the one by the other, the result will evidently be equal to the volume Q discharged under the said conditions, since it will be the product of the velocity by the section. Thus we have formula [N]

$$\sqrt{\frac{266\cdot76\,P\,D}{(0\cdot0238\,L + D)\,d}} \times \frac{3\cdot1416\,D^2}{4} = Q.$$

Squaring the two members, and representing by a the product of the invariable quantities, with the exception of the coefficient 0·0238, it becomes $Q^2 = \dfrac{a\,P\,D^5}{(0\cdot0238\,L + D)\,d}$.

As we want, now, to find the diameter D, we must draw its value from this formula. But as that operation would be very difficult to perform in a direct manner, on account of the two powers D and D^5, we extract the value of D^5 as if D were known, and we find

$$D = \sqrt[5]{\frac{(0\cdot0238\,L + D)\,Q^2\,d}{a\,P}}.$$

And as a is a fixed number, and equal, as may be seen, to

$$\left(\frac{3\cdot1416}{4}\right)^2 \times 266\cdot76 = 164\cdot5576,$$

we extract its fifth root, which is equal to 2·8, whereby we divide the unity, which gives 0·3571; call it 0·36, and taking that number as multiplier from the radical, we arrive at this last expression:

$$D = 0\cdot36\,\sqrt[5]{\frac{(0\cdot0238\,L + D)\,Q^2\,d}{P}}. \qquad [O]$$

Now, in order to work by means of this formula and finally disengage D, this is what may be done: We operate, in the first place, by considering D under the radical equal to 0; we shall thus obtain a first value of D, though rather a weak one. We then recommence the process, this time assigning to D under the radical the approximate value found by the first operation. The second value of D thus obtained, will always be near enough for all practical purposes; if, however, these two successive values were to present a very wide difference, the accuracy of the second value might be tested by performing a third operation wherein that value would in turn be substituted for D under the radical, and might be considered correct if the result of the said operation turned out to be apparently equal to it.

Example.—Be it required to find the diameter D of a pipe under the following conditions:

Length of pipe	L =	100 mètres
Expenditure of gas in a second of time ..	Q =	0·5 cubic mètres
Relative pressure of the gas	P =	0·7 mètres (mercury)
Density of the gas	d =	0·002

Solution. Formula [O].—By considering D under the radical equal to 0, we have

$$D = 0\cdot36\,\sqrt[5]{\frac{(0\cdot0238 \times 100^{\mathrm{m}} + 0) \times 0\cdot25 \times 0\cdot002}{0\cdot7}} = 0^{\mathrm{m}}\cdot101,$$

a first value of D, which we substitute in its place under the radical, in order to perform the second operation, when we find

$$D = 0\cdot36\,\sqrt[5]{\frac{(0\cdot0238 \times 100^{\mathrm{m}} + 0\cdot101) \times 0\cdot25 \times 0\cdot002}{0\cdot7}} = 0^{\mathrm{m}}\cdot101;$$

and as this last result is the same as the first, we may be sure that we have the true value of the required diameter, and no further operation is necessary. As it may appear strange that the same

answer should be obtained from two formulas, one of which contains a quantity more than the other, we must observe that the results are, in reality, different, but that that difference manifests itself only in a series of decimals that are not appreciable in practice. In general, the very disposition of the formula leads us to understand that it is sufficient if the length of the pipe is equal to several times its diameter—which is almost always the case and may be ascertained beforehand—for the result found by the first operation to give the true practical dimension required. A single operation would, therefore, be sufficient; but it is as well to verify it, either by repeating it and giving D its value beneath the radical, or by finding the expenditure of the pipe according to the conditions laid down.

Thus, in order to test the preceding operation, if we seek the velocity of the flow according to the length of pipe, 100 mètres, its diameter 0·101, and the pressure 0·7, we find it to be 62·60 mètres, which, multiplied by 0·008012, area of the circle 9·101, gives 0·501 cubic mètres as the expenditure of the pipe. It is needless to add that this result may be considered to be in strict conformity with the primitive data of the problem.

We shall limit ourselves to this much, considering that we have said all that is useful touching the expenditure of steam and gases; observing, however, that the preceding rules apply where the pipes are straight or curved, but not where they have contractions or sharp angles, such as to destroy a portion of the *vis viva* of the fluid in motion. At the conclusion of this article we shall, as usual, give a list of such authors as may be consulted by those of our readers who are desirous of obtaining more complete notions upon the subject.

Physical Properties of Steam.—The functions of steam motors repose upon the mechanical properties of the aëriform fluid produced by water in its physical change called *the state of steam.* Before studying, therefore, the construction of such machines, it is indispensably necessary that we should give an exact account of the circumstances whereby the phenomenon of the conversion of water into steam is attended, showing the conditions under which it is accomplished; the physical effects that immediately result therefrom; the means of ascertaining their intensity; and, finally, the part taken by the chief imponderable agent, *heat* or *caloric*, and the combustible substances by which this latter is developed. Thus, it is with steam-engines as with hydraulic motors, the motive power is borrowed from natural agents, namely, Caloric and Gravity.

By the means of caloric, an inert liquid, possessing gravity only, is transformed into an expansive gas deriving its power from itself. When that said liquid has been previously elevated by natural forces, gravity seems to use it as a sort of receiver to whom it has entrusted its power in order that it may be restored at a moment when that same liquid may be utilized as a *fall.*

The comparison of these two imponderable agents, brought into play for the purpose of obtaining motive force, is suggestive of a very interesting remark, which is, that, in both cases, one of the two agents, caloric, has been the primal cause of the mechanical effect obtained, since the water, elevated so as to produce a useful fall, was raised solely by the action of heat, which caused it to evaporate so that it might afterwards fall in the shape of rain, forming streams and rivers. It is quite certain that without that cause water would only be known to the world as an uniform level, precisely on account of that gravity which forbids its being raised otherwise than by the development of some mechanical power of corresponding intensity.

It may, therefore, be said that, in the two systems of motors, *water* and *steam*, the first physical expenditure is supplied by caloric.

In hydraulic motors, it effects the change of state by opposing the action of gravity, which will restore later that expenditure of action after the return from the vaporized to the liquid state.

In steam motors, the effect of caloric is immediate, while that of gravity is, for the time, eliminated.

But, even in this latter case, it will be easy to see that the laws of gravity still intervene to measure, in a manner, the effects produced by caloric, which may always be expressed—like every other mechanical work—by the raising of weights.

It becomes, therefore, very easy to understand this transformation of natural powers, so intimately connected that their effects are equal, and exactly compensate one another. This will, perhaps, serve to explain the error into which some persons have fallen, who fancied that it could create an advantageous motor, by raising water with the aid of an artificial vacuum formed by the condensation of steam, and then utilizing it by allowing it to fall upon a wheel or other contrivance.

But it must be evident that a volume of water, raised at the expense of a certain quantity of steam, cannot develop by its fall a greater power than that which would have been produced by the direct use of the steam: it is better, therefore, to adopt this last method.

Definition of Steam.—In nature, bodies present themselves under three different forms,—the solid, the liquid, and the gaseous or aëriform.

Were it not for the particular circumstances under which these bodies are generally maintained, some in one state, some in another, so as to enable us to classify them as above,—with much stronger reason might we say that bodies have no absolute state, but may present themselves indifferently under the one or under the other, which is true.

The normal condition of the medium in which we exist is the sole cause of the distinction that has been admitted into common parlance. We say that water is a liquid; that metals are solids; that air is a gas, and so on; and yet water may become solid as well as gaseous, and metals may be made liquid and even into gas. If air appears not to possess the property of liquefying or solidifying, it is in all probability because we are ignorant of the means requisite—not because they do not exist: other gases are known to be capable of these changes.

So that,—setting aside air for the present,—the physical state of a body is a mere question of temperature. It is certain that, if that of the earth nowhere exceeded one degree centigrade below zero, water would be classed as a solid; and, in the opposite event, if the temperature rose to a sufficient degree of heat, water would be called a gas.

Having explained this in a general manner, we will now occupy ourselves exclusively with that which concerns the changes to which water may be subjected. But, however great our desire may be to simplify as much as possible the study of steam, it will not avail our readers unless they have some knowledge in physics, upon which we cannot enter here. We will therefore suppose that knowledge to exist, embracing the theory of gravity, hydrostatics, the equilibrium of gases, and the phenomena of heat. When occasion requires, moreover, we shall not fail to recall to mind the fundamental laws of those different branches of physics.

Principles of the Formation of Steam.—If a certain quantity of water be placed in a vessel or poured upon the ground in the open air, it will gradually diminish in volume, and, in course of time, disappear altogether unless renewed. The water is then said to have *evaporated*, or transformed itself into steam—that is to say, a gas—invisible like air and mingling with it.

If, in lieu of leaving the water contained in the vessel simply exposed to the temperature of the surrounding atmosphere, we place it over a fire, it begins to heat, then to *boil*, and finally disappears, leaving the vase that contained it completely dry, provided no liquid be added, and that the fire be kept up a sufficient length of time. This time the water is said to have been *vaporized*, which means that it has again been converted into steam, but rapidly, and accompanied by the phenomenon of ebullition.

We see, then, that the transformation of water into steam, or its change from the liquid to the gaseous state, takes place under two different conditions, which are,

1st. *Slow evaporation* in the open air, and without any effervescence;

2nd. *Vaporization*, which signifies the rapid and tumultuous conversion into steam.

These two methods, though differing in appearance, in no way affect the properties of steam. We shall learn, as we proceed, that those conditions only prove that steam is formed at all temperatures; and that, in both cases, when passing from the liquid to the gaseous state, the water acts merely in obedience to a repulsive force of its molecules, which have a constant tendency to separate from one another, overcoming the resistance of the ambient medium. The formation of steam in vacuum fully illustrates this truth, and might, judging from the mere superficial evidence of our senses, constitute a third method, whereas it is but an explanation of one single general phenomenon. We shall also see that this expansive force of the liquid molecules increases with the temperature of the water.

Formation of Steam in Vacuum.—It has been shown by means of the most conclusive experiments that the formation of steam is a permanent property in liquids, and that they would immediately assume that state were they not prevented, under the ordinary conditions of their temperature, by the external pressure of the medium in which they are placed.

Effectually, if water be introduced into a space entirely void of air and where no pressure exists, that is to say, in vacuum, it vaporizes instantaneously; so that of an apparent and fluid body, there only remains an invisible gas like air; and this phenomenon is accomplished no matter what the temperature of the liquid may be. This curious fact is demonstrated by physicists in a very remarkable experiment, and the most satisfactory, perhaps, that could have been devised.

Two mercurial barometers being disposed in the manner indicated by Fig. 848, and both at first marking the atmospheric pressure, like B, a drop of water, whence the air has been carefully expelled by distillation, is introduced into one of the barometrical tubes, say A, at its lower end by the aid of a bent pipe. On account of its specific lightness the drop of water soon reaches the summit of the mercurial column and enters the barometrical chamber or Torricelli's vacuum.

848.

But here, and at the same time, an extraordinary phenomenon takes place: the column of mercury falls while the drop of water disappears, entirely or in part, according to certain conditions which we shall point out presently. Be that, however, as it may, the fall in the mercury is sufficiently great not to be attributed to the mere weight of the liquid, which, by virtue of the immense difference existing between its own density and that of the metal, would, at the most, have caused a depression in the latter scarcely appreciable. Neither can it be accounted for by a certain quantity of atmospheric air disengaged from the water, since this last was previously purged by distillation.

We are, therefore, bound to conclude from this experiment that a gaseous body has been formed in the barometrical chamber, endowed with an expansive force capable of causing the depression *a*, which may be easily measured by means of the barometer B, that has remained intact. That gas is none other than the steam arising from the water, whose molecules, no longer under the influence of atmospheric pressure, have separated from one another with an effort of repulsion which is exactly measured by the barometrical depression *a* resulting therefrom.

So that, in principle, the transition of water to the state of gas or steam is the consequence of a natural expansion of its molecules, which only becomes manifest when it is capable of surmounting the pressure of the ambient medium.

The Influence of Temperature on the Formation of Steam.—The formation of steam in vacuum being a generally established fact, if, now, account be kept of the temperature at which the water was introduced into the barometer, we shall acquire the certitude that the tendency to vaporization varies with that temperature, and that, as the latter increases, so much greater is the depression of the mercurial column. In other terms, the elastic force of steam augments with the temperature of the water by which it was engendered.

The better to impress the mind with this important proposition, let us suppose, in the last experiment, that one decigramme of water was introduced into the barometer at a temperature of + 20 degrees centigrade; we recognize from observation that the depression of the mercurial column would in that case be about 17 millimètres, that is, assuming that the water lost none of

its heat in passing through the mercury; it may, therefore, be said that the pressure exerted by the steam thus formed is equivalent to a small column of mercury of that height; that is, $\frac{11}{760}$ of the entire column, or rather more than $\frac{1}{70}$ of the total atmospheric pressure.

Before enlarging more fully upon these principal properties of steam, it will perhaps be useful if we give a better explanation of what is to be understood by *steam*, and of its real constitution as compared with the notions one might be led to form thereof from a mere casual view of the question. Steam, with its property of expansion, and in that phase of formation in which we have supposed it to be, is in reality a transparent, invisible fluid, like air. The grey or white vapours that escape from a vessel containing boiling water, from the chimney of a locomotive engine, and so forth, are frequently designated as *steam;* but improperly so, since those mists are but an immense agglomeration of microscopic globules composed of a layer of liquid water enclosing steam, and floating in the air, but the whole assemblage of which does not possess the slightest elastic force. They may be regarded as the transitory form assumed by steam in returning to the liquid state caused by relative slow cooling. The phenomenon of fogs is often witnessed in the atmosphere, when the gaseous vapour which it always contains in a greater or less degree is, from some cause or other, partially condensed.

The Maximum Elastic Force of Steam.—It is clear, from the foregoing experiment with the barometer, that, since water only vaporizes so long as it meets with no opposition from the external pressure to which it is subjected, that vaporization ought to cease as soon as the steam already formed has acquired precisely that tension which limits, with a given temperature, the expansion of the liquid molecules. And this, in fact, is what happens. For, if a sufficient quantity of water be introduced into the barometer, the whole of it does not become transformed into steam, but a portion still remains on the top of the column of mercury after the depression of the latter has taken place. In order to attain this result it is necessary that the volume of water introduced should bear a certain relation to the size of the barometrical chamber, including the fall of the mercury. When these conditions have been fulfilled, the chamber is said to be *saturated, that the steam has attained its maximum of expansion or elastic force.* This is tantamount to saying that a sufficient pressure has been engendered to balance the tendency of the water, with its actual temperature, to transform itself through the expansive force of its molecules.

Things being in this state, if by some means we are able to enlarge the space occupied by the steam, fresh quantities of water will be vaporized, and if we continue increasing it, not only will the whole of the water disappear, but the steam will still fill it and yet its pressure will not be completely destroyed.

If we have recourse to the opposite process, and lessen the space, a portion of the water that had been converted into steam returns at once to the liquid state; and should we persevere in reducing it until it equals exactly the volume of the water originally introduced, the entire mass then assumes its primitive form.

These properties, which are an inevitable consequence of what we have said touching the equilibrium between the tension of the steam formed and the natural expansion of the molecules of the liquid mass, are rendered clearly evident by the aid of an instrument called a *well barometer.*

This instrument consists of an ordinary barometer, A, Fig. 849, but whose basin is formed of a deep tube B, widening into a cup at the top and partly filled with mercury, constituting a sort of *well* into which the tube A may be plunged to a considerable length. As the height of the mercurial column is invariable and has for its base the level of the open surface in the basin, it follows, as a matter of course, that, by immersing the tube A in the well, the deeper it goes the smaller in proportion will the barometrical chamber become. If, consequently, we make a drop of water *a* pass to the surface of the mercurial column, as before, the space occupied by the steam will increase or diminish according as we raise or lower the tube in the well. By raising it the drop of water grows gradually smaller, and finally disappears altogether. By continuing thus to augment the barometrical chamber, the mercury—repulsed at first by the elastic force of the steam—will be seen to reascend towards its normal height, but without ever exactly attaining it, even could the tube be indefinitely raised; which clearly proves that the steam continues to occupy the additional spaces offered to it, and always exerts a pressure whose intensity is in the inverse ratio of those spaces.

849.

If now we replunge the tube A deep into the well, we shall see, little by little, the water reappear, and the whole of the steam will return to the liquid state if we immerse the tube sufficiently deep to reduce the vacuum to the dimensions of the drop of water.

This experimental result has caused physicists to say that, although steam, like gases, possesses an indefinite force of expansion which enables it to dilate as the dimensions of the vase containing it are increased; it is not, like most gases, indefinitely compressible; but, that it has a *maximum of elasticity or compression* beyond which it ceases to resist, and, by condensing, returns to the liquid state. But this, however, in no way proves that it has not properties entirely identical with those of gases; for, beyond this fact, which nothing authorizes us to affirm, that gases are susceptible of any amount of compression, it has been observed that several of them liquefy in reality, if subjected to sufficient pressure. Of this number is carbonic acid, for instance, which becomes liquid under a pressure of 45 atmospheres. Other gases liquefy with a much less pressure. But steam offers an advantage seldom or never met with in permanent gases, and that is, the facility of observing the condensation that takes place if we endeavour to compress it beyond a certain limit. It is that limit that has been termed the *maximum of elastic force*, and which varies with the temperature of the liquid by which the steam was generated. It would appear, then, from this, that in vacuum, when the quantity

of liquid is sufficient, the steam acquires immediately its maximum of elastic force, after which the vaporization instantly ceases if no modification of space takes place. By saying that at that moment the space is *saturated*, we use an expression that renders well the idea we wish to convey of the formation of steam which can only continue to disengage itself so long as its own pressure offers no opposition to the continued expansion of the liquid molecules.

The Relation between the Elastic Force of Steam and its Temperature.—Now that the principle of the formation of steam has been rendered intelligible through the evidence afforded by its development in vacuum, it becomes easy to show how its power increases with its temperature. In the foregoing experiment—the instrument used being the barometer, which does not admit of the measurement of a greater pressure than that of the atmosphere balanced by its column of mercury—we were unable to observe the effects of steam at a higher temperature than 100 degrees, in which case the pressure would be sufficient to entirely overcome the said column. The experiments, therefore, could only range between the temperatures of zero—the lowest limit at which water liquefies—and 100 degrees, when, the mercury in the vertical tube being on a level with that in the basin, the instrument ceases to act. This first result has proved, however, of very great importance, since it has afforded an exact knowledge of the general properties of steam, and has enabled us, moreover, to establish a unity of measure of its power. Without rejecting the facility of measurement presented by the barometer, the grand unity, that has been chosen as standard, is the pressure of the atmosphere, to which that of steam becomes equal at a certain temperature, as seen already. Consequently, when the pressure of steam is capable of replacing the column of mercury in balancing the external air, it is said to be equal to *one atmosphere*. That pressure, as expressed by weight and unity of surface, is, we know, equal to 1·0333 kilogramme on every square centimètre. It is simply the weight of a column of mercury measuring 76 centimètres in height and 1 centimètre square at the base.

If, as we have explained elsewhere, water, when heated in the open air, cannot exceed the temperature of 100 degrees centigrade, the case assumes a very different aspect when it is confined in a close vessel from which the steam is unable to escape into the atmosphere as fast as it is formed. The temperature of the water may then be heightened, giving forth steam whose pressure increases, we might almost say, indefinitely.

In order to furnish a first demonstration of this fact, physicists have recourse to a very simple experiment, of which we must say a few words.

A tube, A, Fig. 850, bent in the form of an U, but having its branches of unequal length—the longer being open to the air, while the shorter is hermetically closed—is partially filled with mercury, and a drop of water is made to pass to the summit of the column in the sealed end, as seen at *a*.

850.

Having made these arrangements, if we now plunge the instrument into an oil bath at a temperature greater than 100 degrees, steam begins to form, spreading from *a* to *m n*, and thrusting back the mercury which rises in the longer branch of the tube to a certain height *s l*. It then becomes evident that the steam exerts a pressure superior to that of the atmosphere, since when in its liquid state it bore that pressure transmitted through the mercury, but repulsed it as soon as it became transformed.

Its real pressure is therefore equal to that of the atmosphere plus the column of mercury H, measured from the open surface *s l* to the horizontal line *m n*, passing through the summit of the column in the short branch of the tube.

Be it granted, for example, that, in the above experiment, the larger column of mercury has reached a height H equal to 45 centimètres; how should we express ourselves in order to indicate the pressure of the steam that has been formed, allowance for the expansion of the mercury not being taken into consideration?

With a barometer indicating that, at the moment of the experiment, the atmospheric pressure is balanced by a column of mercury 76 centimètres in height, the steam will have overcome a resisting column of $76 + 45 = 121$ centimètres. In order to establish the relation between the height of that pressure and that of the atmosphere, we say, $\frac{121}{76} = 1{\cdot}592$; meaning that the pressure of the steam is equal to 1 atmosphere plus 592 thousandths.

As regards the expression of the pressure by weight and unity of surface, adopting the centimètre square for the latter, it is sufficient to know the density of the liquid raised, and to ascertain its weight according to its volume. The density of mercury being 13·598, or 13·598 grammes for a cubic centimètre, we should have $13{\cdot}598 \times 121 = 1645$ grammes. We then say that the steam exerts a pressure represented by a weight equal to 1·645 kilogramme upon every centimètre square.

Let us remark, in order that no doubt may present itself to the mind respecting the condition of vacuum laid down just now for the formation of steam,—but which does not apply in the above experiment,—that it must be remembered that a vacuum does not otherwise modify the phenomenon of the generation of steam, beyond allowing its instantaneous accomplishment, and at the lowest temperatures, even that of freezing. Consequently, the properties observed are the same in both instances. Were it possible for us to transport ourselves to some place where the barometrical pressure could reach a height of 121 centimètres, the experiment might be performed with that instrument, and the results obtained would be precisely identical.

Although the last experiment has enabled us to note the pressure of steam for temperatures a little above 100 degrees, it would not be so were it to become very much greater; for, as steam rapidly acquires very considerable pressure, it is more than probable that the instrument would not be able to resist it.

The first men, after English accurate investigators, to thoroughly investigate this question in France were the celebrated Arago and Dulong, to whom the Academy of Sciences entrusted the

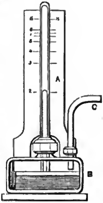
important and useful mission of ascertaining the elastic force of steam throughout the most extended scale of temperatures possible. That laborious work was only terminated in 1830.

This is how these illustrious savants operated so as to obtain high degrees of temperature, and be able, at the same time, to measure the corresponding elasticity of the steam.

The water was enclosed in a boiler made of strong sheet iron, perfectly air-tight, and fixed in a brick furnace. Two gun-barrels, open at the top and closed at the bottom, were then inserted into the lid, descending, the one to the lower part of the vessel, the other to the upper, where the steam was confined. Both were filled with mercury, which acquired necessarily the same temperature as the fluid into which the barrels were plunged, and which could be easily measured by the aid of thermometers so disposed as to suffer no loss by cooling. Being thus in a position to know at any moment the temperature of the liquid and of the steam arising from it, a communication was established between the latter and an instrument suitable for measuring its corresponding tension.

That instrument is what has been called later a *Condensed-air Manometre*, and is composed, in principle, of a stout glass tube A, Fig. 851, closed at its upper extremity, while its lower one, which is open, dips into a basin B, containing mercury. This tube is carefully adjusted to the basin, so as to cut off all communication with the external atmosphere. A second tube C, similarly fitted, has one of its ends inserted likewise into the basin, but without dipping in the mercury; while the other is connected with the vessel in which is the fluid whose elastic force has to be ascertained.

851.



In order to understand the working of the manometre, let us suppose, before beginning the experiment, that perfect communication exists between the several parts, and that the whole is filled with atmospheric air; it is then clear that the level of the mercury within the glass tube will be the same as that in the basin, the pressure being equal throughout. Soon, however, the temperature of the liquid beginning to rise, steam is formed in the boiler, and the air it contained is thereby gradually expelled through an outlet temporarily reserved for that object. So long as the temperature has not reached that point at which the tension of the steam exceeds that of the atmosphere, the level of the mercury remains unaltered; but, from the instant that occurs, from the special arrangement of the apparatus, the temperature of both the liquid and the steam augments, as well as the elastic force of the latter: the mercury is then seen to rise in the tube on account of that excess of tension, which is felt alike in the basin containing the mercury and in the vessel where the steam is generated. But, as the mercury rises, it necessarily compresses the air confined in the upper portion of the tube, and whence it is unable to escape: the elastic force of that compression must be the same as that of the steam, by virtue of the equal transmission of pressure, barring a correction on account of the weight of the column of mercury raised. This compression of the air above the mercurial column is, therefore, the measure of the elastic force of the steam; and is the more easily determinable that air is compressed in accordance with a well-known law, discovered by Mariot, and defined in the following terms:—

The volumes of gases are inversely proportional to their pressures.

We shall revert again to that law, to which we merely allude for the better intelligence of the present experiment.

Consequently, if we adopt as unity the volume of air contained in the tube at the commencement of the operation, with the ordinary atmospheric pressures, when, by the rising of the mercury, that volume has been reduced one-half, we shall conclude that it supports a double pressure, or 2 atmospheres; when it has been reduced to one-third, that the pressure is triple, or equal to 3 atmospheres; when to one-quarter, 4 atmospheres, and so on.

This disposition of the manometre enables us, therefore, at any moment to ascertain the elastic force of the steam formed, while the thermometers give its temperature. We may add that the experiments have been carried as far as 24 atmospheres. From these experiments and others, a very complete Table has been made of the corresponding elastic force of steam for various temperatures and also a formula whereby the intermediate quantities may be calculated. We subjoin that portion of the Table which is most likely to prove useful in practice. The elastic forces given are maxima, that is to say, those, at each temperature, where the steam *saturates the space* and would commence returning to its liquid state if an attempt were made to compress it. The Table is divided into two parts, the first comprising the elastic forces of steam for temperatures ranging from 0 to 100 degrees, the second the temperatures corresponding to elastic forces that vary from 1 to 50 atmospheres.

A third Table has been added to these, based upon calculation, for pressures ranging between 100 and 1000 atmospheres. Although it is the opinion, even of savants, that the numbers it contains are not to be relied upon, since they have not the sanction of experiment, still we give it, that it may serve for comparison.

The two first Tables, on the contrary, afford all the guarantee demanded in practice; and from more recent researches, made by M. Regnault, it turns out that, with the exception of a few slight differences, their correctness may generally be depended upon.

In examining these Tables with a little attention we are struck with a very remarkable result,—it is the rapidity with which the tension of steam increases, compared with its temperature, and how very far the two effects are from being proportional. This fact may be rendered still more apparent by means of a graphic tracing, which, being constructed with the assistance of the numbers given in the Tables, brings it more prominently before the understanding.

TABLE I.—THE MAXIMUM ELASTIC FORCE OF STEAM FOR TEMPERATURES FROM 0 TO 100 DEGREES CENTIGRADE.

Degrees, centigrade.	Tension of Steam in millimètres.	Pressure in kilos. on 1 centimètre square.	Degrees, centigrade.	Tension of Steam in millimètres.	Pressure in kilos. on 1 centimètre square.	Degrees, centigrade.	Tension of Steam in millimètres.	Pressure in kilos. on 1 centimètre square.
0	5·059	0·0069	34	38·254	0·0520	68	209·440	0·28454
1	5·398	0·0074	35	40·404	0·0549	69	219·060	0·29761
2	5·748	0·0078	36	42·743	0·0581	70	229·070	0·31121
3	6·123	0·0084	37	45·038	0·0612	71	239·450	0·32532
4	6·523	0·0089	38	47·759	0·0646	72	250·230	0·33996
5	6·947	0·0094	39	50·147	0·0681	73	261·430	0·35518
6	7·396	0·0101	40	52·998	0·0720	74	273·030	0·37094
7	7·871	0·0107	41	55·772	0·0758	75	285·070	0·38632
8	8·375	0·0114	42	58·792	0·0799	76	297·570	0·40428
9	8·909	0·0122	43	61·958	0·0818	77	310·490	0·42184
10	9·475	0·0129	44	65·627	0·0892	78	323·890	0·44004
11	10·074	0·0137	45	68·751	0·0934	79	337·760	0·45888
12	10·707	0·0146	46	72·393	0·0983	80	352·080	0·47834
13	11·378	0·0155	47	76·205	0·1035	81	367·000	0·49860
14	12·087	0·0165	48	80·195	0·1090	82	382·380	0·51950
15	12·837	0·0170	49	84·370	0·1166	83	398·280	0·54110
16	13·630	0·0186	50	88·743	0·1206	84	414·730	0·56345
17	14·468	0·0197	51	93·301	0·12676	85	431·710	0·58652
18	15·353	0·0209	52	98·075	0·13325	86	449·260	0·61086
19	16·288	0·0222	53	103·060	0·13999	87	467·380	0·63498
20	17·314	0·0235	54	108·070	0·14710	88	486·090	0·66040
21	18·317	0·0250	55	113·710	0·15449	89	505·380	0·68661
22	19·447	0·0265	56	119·390	0·16220	90	525·28	0·71364
23	20·577	0·0281	57	125·310	0·17035	91	547·80	0·64152
24	21·805	0·0297	58	131·500	0·17866	92	566·95	0·77026
25	23·090	0·0314	59	137·940	0·18736	93	588·74	0·79986
26	24·452	0·0334	60	144·660	0·19653	94	611·18	0·83035
27	25·881	0·0353	61	151·700	0·20610	95	634·27	0·86172
28	27·390	0·0374	62	158·960	0·21586	96	658·05	0·89402
29	29·045	0·0396	63	165·560	0·22639	97	682·59	0·92736
30	30·643	0·0418	64	174·470	0·23758	98	707·63	0·96138
31	32·410	0·0440	65	182·710	0·24828	99	733·46	0·99448
32	34·261	0·0465	66	191·270	0·25986	100	760·00	1·03253
33	36·188	0·0492	67	200·180	0·27196			

TABLE II.—OF THE TEMPERATURES OF STEAM FOR TENSIONS FROM 1 TO 50 ATMOSPHERES.

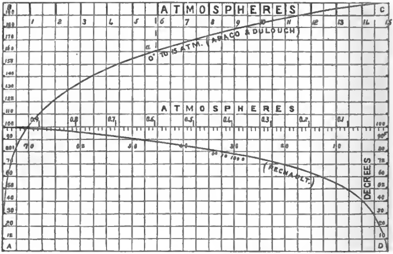
Elastic Forces expressed in Atmospheres of 76 cents. of mercury.	Corresponding Temperatures given by the Centigrade Mercurial Thermometer.	Pressure in kilogrammes on a centimètre square.	Elastic Forces expressed in Atmospheres of 76 cents. of mercury.	Corresponding Temperatures given by the Centigrade Mercurial Thermometer.	Pressure in kilogrammes on a centimètre square.
1	100	1·033	13	193·7	13·429
1½	112·2	1·549	14	197·19	14·462
2	121·4	2·066	15	200·48	15·495
2½	128·8	2·582	16	203·60	18·528
3	135·1	3·099	17	206·57	17·561
3½	140·6	3·615	18	209·4	18·594
4	145·4	4·132	19	212·1	19·627
4½	149·06	4·648	20	214·7	20·660
5	153·08	5·165	21	217·2	21·693
5½	156·8	5·681	22	219·6	22·726
6	160·2	6·198	23	221·9	23·759
6½	163·48	6·714	24	224·2	24·792
7	166·5	7·231	25	226·3	25·825
7½	169·37	7·747	30	236·2	30·990
8	172·1	8·264	35	244·85	38·155
9	177·1	9·297	40	252·55	41·320
10	181·6	10·33	45	259·52	46·485
11	186·03	11·363	50	265·89	51·650
12	190	12·396			

TABLE III.—OF THE TEMPERATURES OF STEAM FOR TENSIONS FROM 100 TO 1000 ATMOSPHERES.

Elastic Forces expressed in Atmospheres.	Corresponding Temperatures.	Pressure in kilos. on a centimètre square.	Elastic Forces expressed in Atmospheres.	Corresponding Temperatures.	Pressure in kilos. on a centimètre square.
100	311·36	103·30	600	462·71	619·8
200	363·58	206·60	700	478·45	723·1
300	397·65	309·90	800	492·47	826·4
400	423·57	413·20	900	505·16	929·7
500	444·70	516·50	1000	516·76	1033·0

The first idea of a tracing of this nature belongs to M. Clément-Désormes, from whose hints M. Leblane made a diagram which may be seen in the galleries of the Conservatoire des Arts et Métiers, Paris. The one which we here reproduce, Fig. 852, comprises, in addition, a special tension curve, from 0 to 1 atmosphere, after the table drawn up by M. Regnault.

852.



The principle of the tracing is extremely simple. The vertical scale A B is divided into equal parts indicating a succession of temperatures from 0 to 200 degrees. The horizontal line B C is in like manner divided into equal parts corresponding to pressures expressed in atmospheres. Points have been marked upon the diagram where the vertical and horizontal lines meet, that is, at the intersection of the abscisses and ordinates passing through the temperatures and tensions which face one another in the preceding Tables, and those points united by the curve A C.

A second curve D E has been traced to correspond with the tensions ranging between 0 and 100 degrees, and to enable the results to be more clearly nnderstood hy enlarging the scale. Effectually, the total length of the diagram which, on line B C corresponds to 15 atmospheres, represents but one only with respect to the second curve D E, whose graduated scale of tensions is on the line F E, and gives at once the fractions of an atmosphere of 760 millimètres of mercury, and the absolute heights of that liquid expressed in centimètres.

Thus, hy this twofold graduation of the scale we see simultaneously to what fraction of an atmosphere steam at a given temperature corresponds, and what is its equivalent in centimètres of mercury.

For instance, let us take a temperature of 70 degrees in the scale D F, and from its intersection *b* with the curve D E draw a vertical line till it meets the scale E F, and we shall find that it answers in that scale to a mercurial height of 23 centimètres and to 0·3 atmospheric pressure.

It is evident that the inverse operation, that is, to find the temperature for a proposed tension, is performed exactly in the same manner, the disposition of the diagram being equally adapted for both purposes.

The construction of these curves is sufficient to show the rapidity with which the tension of steam increases, since, were it proportional, the points of intersection of the lines passing through the temperatures and tensions would be situated on a straight line drawn from A to C. But this is far from being the case, since we see hy the Tahle that the elastic force of steam, at a

temperature of 82 degrees, being equal to 382 millimètres of mercury, or about half an atmosphere; it becomes double or 1 atmosphore at 100 degrees, 2 atmospheres at 121 degrees, 3 atmospheres at 135 degrees, and finally it reaches 24 atmospheres before its temperature has risen to 225 degrees.

Steam is, therefore, a power that requires to be used with great precaution, because, after certain limits, a few degrees of temperature suffice to double its pressure, and may entail serious disaster. This is known to all mechanicians, and should particularly be borne in mind by stokers for their own security.

Density of Steam.—The density of steam forms a very important item in the study of engines, since it teaches what are the quantities of water requisite to feed a given motor.

Before giving the mere list of values that correspond to the different densities of steam, according to its tensions and temperatures, some explanation is necessary so as to establish clearly the condition in which it is when a density of any kind is applied.

Steam may be supposed to be in two situations: 1st. Enclosed in a vessel together with a certain quantity of the liquid by which it was generated; 2nd. Enclosed in a vessel of which it fills the entire space without any of the liquid being present.

First condition.—When a vessel contains, at the same time, both liquid and steam, what will happen if the supply of caloric be continued? The water will generate more steam, which will combine with that already formed; but, as the steam occupies a much greater space than the water that has been vaporized, the result will be that, since the primitive volume is only augmented by an imperceptible quantity, its pressure will notably increase, and in a manner analogous to that of a gas when condensed into a given capacity. This effect is further enhanced by the tendency of the first-formed steam to expand on account of the elevation of temperature.

Second condition.—If a vessel, containing steam but no liquid, be subjected to an increase of temperature, the steam will make an effort to expand like a permanent gas, and its tension will increase in the same proportion. Only, in this latter case, the progression of the elastic forces will not be so rapid as in the former, because it results only from the tendency to expansion, which, within certain limits, is proportional to the increased temperature.

Consequences.—Under the first of these two conditions, where the space occupied by the steam, though remaining perceptibly unaltered, is gradually charged with fresh quantities of vaporized water as the temperature and tension increase, it is evident that the density of that steam must vary also, which is not the case under the second condition, where it tends only to expand, but receives no additional charge. The peculiar density of steam is derived, therefore, from the first condition, wherein each new tension corresponds to fresh quantities of vaporized water.

We are indebted to Gay-Lussac for the most complete notions on this subject. The experimental researches made by that illustrious savant enabled him to construct a formula by the aid of which he calculated a table of densities, taking those by MM. Arago and Dulong, touching the relation between temperature and tension, as the base of his operations.

In order thoroughly to understand the application of densities, it must be remembered,

1st. That the said densities correspond to the volumes occupied by the steam when at its maximum of elastic force, after which any mechanical compression would cause it to return to the liquid state;

2nd. That a given weight of steam is exactly equal to that of the water whence it was formed.

Table I.—Of the Densities and Volumes of Steam at its Maximum of Elastic Force, from 0 to 100 degrees.

The density of water at 0° being taken as unity.

Temperature.	Tension in millimètres.	Density.	Volume.	Temperature.	Tension in millimètres.	Density.	Volume.
0	5·059	0·00000540	182323	23	20·577	2021	49487
1	5·393	573	174495	24	21·805	2133	46877
2	5·748	609	164332	25	23·090	0·00002252	44411
3	6·123	646	154342	26	24·452	2376	42084
4	6·523	686	145886	27	25·881	2507	39895
5	6·947	727	137488	28	27·390	2643	37838
6	7·396	772	129587	29	29·045	2794	35796
7	7·871	818	122241	30	30·643	2938	34041
8	8·375	867	115305	31	32·410	3097	32291
9	8·909	919	108790	32	34·261	3263	30650
10	9·475	0·00000974	102670	33	36·188	3435	29112
11	10·074	0·00001032	99202	34	38·254	3619	27636
12	10·707	1092	91564	35	40·404	3809	26253
13	11·378	1157	86426	36	42·743	4017	24897
14	12·087	1224	81686	37	45·038	4219	23704
15	12·837	1299	77008	38	47·579	0·00004442	22513
16	13·630	1372	72913	39	50·147	4666	21429
17	14·468	1451	68923	40	52·998	4916	20343
18	15·353	1534	65201	41	55·772	5156	19396
19	16·288	1622	61654	42	58·792	5418	18459
20	17·314	1718	58224	43	61·958	5691	17572
21	18·317	1811	55206	44	65·627	6023	16805
22	19·417	1914	52260	45	68·751	6274	15938

TABLE I.—OF THE DENSITIES AND VOLUMES OF STEAM, &c.—*continued.*

Temperature.	Tension in millimètres.	Density.	Volume.	Temperature.	Tension in millimètres.	Density.	Volume.
46	72·393	6585	15185	74	273·030	22794	4387
47	76·205	6910	14472	75	285·070	23789	4204
48	80·195	7242	13809	76	297·570	24702	4048
49	84·370	7602	13154	77	310·430	25699	3891
50	88·742	0·00007970	12546	78	323·890	26739	3741
51	93·304	0·00008354	11971	79	337·760	27789	3599
52	98·075	8753	11424	80	352·080	0·00028889	3462
53	103·060	9174	10901	81	367·000	30025	3331
54	108·270	0·00009606	10410	82	382·380	31195	3206
55	113·710	0·00010054	9946	83	398·280	32399	3087
56	119·390	10525	9501	84	414·730	33637	2973
57	125·310	11011	9082	85	431·710	34916	2864
58	131·500	11523	8680	86	449·260	36237	2760
59	137·940	12044	8303	87	467·380	37590	2660
60	144·660	12599	7937	88	486·090	38984	2565
61	151·700	13179	7591	89	505·380	40417	2474
62	158·960	13760	7267	90	525·280	41891	2387
63	166·560	14374	6957	91	545·800	0·00043405	2304
64	174·470	15010	6662	92	566·950	44956	2224
65	182·710	15668	6382	93	588·740	46556	2148
66	191·270	16356	6114	94	611·180	48201	2075
67	200·180	17060	5860	95	634·270	49886	2005
68	209·440	17797	5619	96	658·050	51613	1938
69	219·060	18566	5380	97	682·590	53388	1873
70	229·070	19355	5167	98	707·630	55191	1812
71	239·450	20174	4957	99	733·460	57055	1751
72	250·230	21013	4759	100	760·000	0·00058955	1696
73	261·430	21889	4569				

TABLE II.—THE DENSITIES AND VOLUMES OF STEAM FROM 1 TO 50 ATMOSPHERES.

Temperature.	Elastic Force expressed in Atmospheres.	Density.	Volume.	Temperature.	Elastic Force expressed in Atmospheres.	Density.	Volume.
100	1	0·0005895	1696	193·7	13	0·006107	163·74
112·2	1·5	0·0008563	1167·8	197·2	14	0·006527	153·10
121·4	2	0·0011147	897·9	200·5	15	0·006944	144·00
128·8	2·5	0·0013673	731·39	203·6	16	0·007359	135·90
135·1	3	0·0016150	619·19	206·6	17	0·007769	128·71
140·0	3·5	0·0018589	537·96	209·4	18	0·008178	122·28
145·4	4	0·0020997	476·26	212·1	19	0·008583	116·51
149·1	4·5	0·0023410	427·18	214·7	20	0·008986	111·28
153·1	5	0·0025763	388·16	217·2	21	0·009387	106·53
156·8	5·5	0·0028091	355·99	219·6	22	0·009785	102·19
160·2	6	0·0030402	328·93	221·9	23	0·010182	98·21
163·5	6·5	0·0032683	305·98	224·2	24	0·010575	94·56
166·5	7	0·0034981	286·12	226·3	25	0·010968	91·17
169·4	7·5	0·0037217	268·82	236·2	30	0·012903	77·50
172·1	8	0·0039434	253·59	244·8	35	0·014663	68·20
177·1	9	0·0043865	227·98	252·5	40	0·016644	60·08
181·6	10	0·0048226	207·36	259·5	45	0·018497	54·06
186·0	11	0·0052557	190·27	265·9	50	0·020306	49·31
190·0	12	0·0056834	175·96				

TABLE III.—THE DENSITIES AND VOLUMES OF STEAM FROM 100 TO 1000 ATMOSPHERES.

Temperature.	Elastic Force expressed in Atmospheres.	Density.	Volume.	Temperature.	Elastic Force expressed in Atmospheres.	Density.	Volume.
311·36	100	0·037417	26·72	462·71	600	0·17791	5·621
363·58	200	0·068635	14·570	478·45	700	0·20318	4·921
397·65	300	0·097671	10·238	492·47	800	0·2279	4·387
423 57	400	0·12534	7·978	505·16	900	0·2522	3·965
444·70	500	0·15202	6·578	516·76	1000	0·276	3·622

The use of these Tables is easily understood. For the present, let it be observed that, as all the values have not been derived from actual experiments, it is possible that some may not be in strict accord with real facts; but, as they set forth this property, that the density of steam increases with the tension and temperature, we conclude therefrom that, with a temperature sufficiently high, it is probable that it would equal that of water; that is to say, that a certain quantity of water might pass to the state of steam without augmentation of volume; "in which case it would have," says M. Pouillet, in his excellent 'Treatise on Physics,' "a tension of several hundreds—perhaps of several thousands—of atmospheres." We learn from that savant that an experiment has been made by M. Cagnard de la Tour demonstrating a fact that seems to be an approach towards that hypothetical result. It is thus: a strong glass tube is filled to be a quarter of its capacity with water; this done, it is exhausted of air and sealed hermetically. It is then exposed to a gradually-increasing temperature, when, on arriving at a certain temperature, the water seems to vanish altogether, and the tube appears empty; but, on slightly cooling, the liquid returns almost suddenly . . . ; this effect is produced at a temperature nearly equal to that which causes the fusion of zinc, or 360 degrees centigrade. In other terms, the whole of the water vaporizes in a space only four times its volume!

The Ebullition of Water.—In order that the fundamental properties of the formation of steam may be well understood, it is necessary that the phenomenon of ebullition be fully explained: but, as that explanation would not have been intelligible without a portion of the preceding notions, we have been compelled to give them first.

Everybody knows what takes place when we heat, during a sufficient length of time, a vessel containing water in free communication with the atmosphere. At first, a vapour is seen to rise that seems to emanate from the surface of the liquid, getting more and more intense as the water becomes warmer. Then a tremor of the surface is produced, accompanied by a peculiar noise which has been called *the singing* of the liquid; and finally bubbles, similar to air-bubbles, form in that part of the vessel that is nearest to the fire, then rise to the surface, where they burst, giving forth fresh vapour. Those bubbles are nothing else than certain molecules of the liquid being transformed into steam, and which, meeting with an equal pressure on all sides, from the water itself and from the atmosphere, offers an equal resistance in return, and so assume the spherical form in which they are seen to ascend.

Now, an immediate consequence may be drawn from the simple observation of this fact, which is, that the pressure of the steam, in order that it may form these bubbles, must be greater than that of the liquid mass and of the atmosphere acting upon its surface. Consequently, if that pressure, which we will designate as that of ebullition, corresponds to an ascertained fixed temperature, it is evident that—the atmospheric pressure remaining unchanged—the liquid must always reach that temperature before the ebullition can manifest itself.

That, in fact, is rigidly what takes place. Every time that water boils in the open air, its temperature is always the same with a uniform barometrical pressure. If it has been found that water at 100 degrees centigrade generates steam under the atmospheric pressure, it is simply because we have chosen to mark the hundredth degree of the centigrade thermometer under a barometrical pressure of 76 centimètres of mercury.

The ebullition of a liquid can, therefore, only take place so long as the steam it is capable of emitting balances the united pressures of the ambient medium wherein it is situated, and of its own mass or load above the surface heated.

This definition of the phenomenon suffices to show that the degree of temperature at which the ebullition of a liquid may be produced is variable, and changes according to the pressure of the medium, since vaporization takes place at any degree. If a perfect vacuum could be established, and water at the freezing-point placed in it, it would immediately begin to boil; but, in practice, it is never perfect, so that ebullition only takes place at a few degrees above zero. On the summit of Mont Blanc, where the atmospheric pressure is reduced from 760 millimètres to about 417, measuring by the barometer from the level of the sea, water would begin to boil at the temperature of 84 degrees, at which, as we have shown in one of the foregoing Tables, page 415, the elastic force of steam is equal to 414 millimètres, or a little more than half the pressure of an atmosphere.

Finally, the greater the pressure to which water is subjected, the greater is its heat when boiling, and *vice versâ*; that is why the temperature of boiling water is higher in a valley than on a mountain. Let us add, by way of corollary, that, the conditions being similar, the expansive force of the steam of all liquids is equal at the moment of ebullition. This is an axiom, since the very fact of the ebullition sufficiently testifies that the elastic force of the steam has become equal to that of the medium in which it has formed.

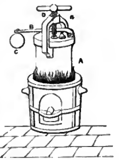
Fixity of the Temperature at Boiling-point.—At whatsoever temperature ebullition may be produced, so long as it continues that temperature remains unchanged; in other words, the liquid ceases to become heated the instant it begins to boil, always provided that the pressure of the medium undergoes no alteration. This fact is easily explained if we reflect that, as the liquid has acquired a temperature at which it can no longer subsist without change of state, all fresh quantities of caloric supplied are absorbed by the formation of steam. Therefore, under the ordinary conditions in which we boil water, it acquires, when pure, a temperature of 100 degrees, and retains it without variation. In reality, it would only reach that temperature on a level with the sea; but in most European towns, which are necessarily higher, it does not exceed 99·8 degrees. This difference is unimportant with regard to the point under consideration.

In order to increase the temperature, it would be necessary to create an artificial atmosphere of proportionally greater pressure than the ambient one, which is precisely what is obtained, in the case of steam-engines, by hermetically closing the vessel that contains the liquid. The steam that is disengaged then becomes compressed, and prevents the generation of further quantities except under a higher temperature. That is what took place in the experiments made by

MM. Arago and Dulong to which we have previously alluded. We may add that, if the vessel in which the water is vaporized remains closed, without any expenditure of steam, the ebullition cannot even be effected, as the pressure, increasing every moment, prevents the formation of the bubbles.

Papin's Saucepan.—To obtain an experimental demonstration of this phenomenon, the apparatus known by the name of *Papin's Saucepan*, after its inventor, may be used. That apparatus consists simply of a vessel A, Fig. 853, made of metal, and having very great power of resistance. It is perfectly closed, with the exception of a small hole in the lid, fitted with a valve which a lever B, disposed like a Roman balance, keeps securely in its place. This arrangement is well known, being none other than that of the actual safety-valve, which is composed of the lever whose pressure is exerted upon the valve *a*, situated between its articulated attachment and the weight C at its other extremity. The valve, therefore, can only rise out of its place by overcoming the resistance opposed by the lever in virtue of its load and the ratio of the two arms.

853.



The lid of the vessel A is also very firmly secured by means of a fastening D, bent in the form of an arc, and supplied with a pressure-screw, by the aid of which the lid is made to press hermetically upon the edge of the vase, care having been taken to insert between the two a round of soft metal for that purpose.

The apparatus being thus constructed so as to resist a strong internal pressure, it is filled to about one-third of its capacity with water, and placed over a fire after being carefully closed. Gradually the temperature of the water begins to increase; but, as the steam that forms is unable to escape, except upon the condition that its pressure is capable of opening the valve, it becomes compressed, and soon the ebullition is unable to proceed.

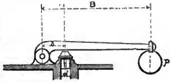
If, at the moment when the internal pressure appears to reach that point where it is likely to raise the valve, the latter be opened, or a cock attached to the lid be suddenly turned on, the ebullition immediately manifests itself, and the steam escapes with impetuosity in the form of a jet which may reach a height of eight or ten mètres, according to the amount of pressure within the vessel. The liquid cools to 100 degrees, and soon the whole of it goes off in steam, provided that the action of the fire be continued sufficiently long, and that the valve or cock be left open.

The pressures to which the steam may reach under this condition are very considerable, and depend, moreover, upon the weight wherewith the valve is loaded.

Without anticipating upon the details that will be given later touching this important apparatus, we may at once make a few remarks as to the conditions that have to be fulfilled in order that it may meet a given pressure.

Fig. 854 shows the arrangement of the safety-valve, where we will call B the distance from the centre of articulation to the centre of the weight, or the long arm of the lever; *b*, the distance from the same point to the centre of the valve, or the short arm of the lever; *d*, the diameter of the orifice closed by the valve; *p*, the intensity of the weight suspended from the lever; P, the total upward pressure exerted by the steam upon the valve over a circular surface whose diameter is *d*.

854.



We first of all find, by the arrangement of the lever, and in accordance with its general properties, that the downward pressure P′ which it exerts upon the valve is equal to $P' = p \times \frac{B}{b}$, supposing, for the moment, the lever itself to be without weight.

In order that the valve may be kept in its place until the given pressure has been attained, it is necessary that the efforts P′ and P be equal. But the effort P is always easily known, for it results from the said pressure and the diameter of the orifice *d*, whose area may be calculated.

Consequently, the operation resolves itself into finding the effort P, by means of the conditions laid down, and substituting it for P′ in the preceding equation, which will enable us to calculate one of the three dimensions *p*, B, or *b*, the two others being fixed *a priori*.

Example.—Be it required to find the conditions of a valve having to bear a pressure of 20 atmospheres.

Let us suppose the diameter *d* of the orifice to be equal to 1 centimètre.

"	"	long arm B of the lever	"	30	"
"	"	short arm *d* of the lever	"	2	"

what will be the intensity of the weight?

A pressure of 20 atmospheres represents an effort equal to $1^k \cdot 0333 \times 20 = 20^k \cdot 666$ for every centimètre square; consequently, the diameter of the valve being 1 centimètre, the pressure exerted upon it will be equal to the product of the corresponding section, in square centimètres, by the above pressure, from which pressure we must deduct that necessarily exerted downwards by the external atmosphere, and which is equal to 1.

We therefore have for the effective effort P,

$$P = (20 - 1)\ 1 \cdot 0333 \times 0 \cdot 7854 \times 1^2 = 15 \cdot 42 \text{ kilogrammes.}$$

From this it results that adapting the preceding relation with p for the unknown quantity, we shall have for its value, $p = P'$ or $P \frac{b}{B} = 15^k \cdot 42 \times \frac{2}{30} = 1 \cdot 028$ kilogramme.

In conclusion, it will be observed that the displacement of the weight upon the lever would be sufficient to alter the conditions of the problem, and consequently the result, since the arms of the lever would no longer bear the same ratio to one another.

The valve, then, is the only cause that limits the pressure which the steam mey acquire in the experiment of Papin's saucepan; apart, of course, from the capability of resistance of the vessel itself. By this method pressures of 40 and even 50 atmospheres have been obtained, that is to say, steam exerting the enormous effort of 50 kilogrammes on the square centimètre, or 500,000 kilogrammes on the square mètre.

Influence of Substances in Dissolution upon the Temperature of the Boiling-point.—Among the several causes that intervene sometimes to modify by a few degrees the ebullition of water, the pressure of the medium remaining the same, we may cite salts and other substances in dissolution, which retard the boiling-point to a certain extent, according to the degree of saturation. Thus, water saturated with sea-salt is hotter at the moment of ebullition than when it is pure, or even when it contains merely bodies in suspension that are not chemically combined with it.

Considered from the purely practical point of view that occupies us at present, this phenomenon has, however, no very great importance; since, supposing the saturation to be complete, which is rarely the case with water used for steam-engines, the temperature of the boiling-point is increased only by 9 degrees. Marine engines, and certain permanent engines situated near the sea, are fed, however, from its waters, which contain salt in large proportions. But, in this case, the principal objection is not the alteration of temperature, but the danger of explosion from the deposits that would form were the generator not kept constantly clean.

Method of Vaporizing a Liquid that contains Foreign Matter.—When a liquid containing foreign matter, in a state of mixture, but without chemical combination, is subjected to heat, the vaporization takes place in succession for each of the substances forming the mixture, and in the order of temperature that corresponds with its respective boiling-point.

If, for instance, we expose water containing substances more volatile than itself to the action of heat, those substances will be liberated first, while the mass of the liquid remains at the temperature that suits their ebullition; then, when they have disappeared, the temperature of the water will begin to rise till it reaches the boiling-point.

In the opposite case, where the substances are less volatile than water, the latter vaporizes first, at the temperature suited to its ebullition, under reserve of the slight modification that may result from the mixture or the dissolution, as above mentioned.

This fact will be very easily understood by observing that so soon as the liquid mass has acquired the temperature necessary for the ebullition of the most volatile of the liquids composing the mixture, in order that the latter may be vaporized, it absorbs all the fresh quantities of heat supplied, and which are thus prevented co-operating in elevating the temperature of the entire mass.

Therefore is it that vaporized water is considered pure, whatever may have been the foreign matter held in solution, since this last either has or will disappear, but never at the same time as the water.

Such are at least the practical conditions we have to take into consideration regarding the subject that occupies our present attention. Steam-engines present constant examples of the principle whereby water is isolated, by vaporization, from the substances mixed with it or held in solution. Everybody, indeed, is aware of the fact of the incrustation of steam-boilers by the sedimentary deposits resulting from the continued abandonment by the water, as it vaporizes, of the various calcareous and saline substances which it contains in different proportions. The feeding of boilers with sea-water gives rise to considerable deposits of sea-salt, separated from the water at the moment of vaporization. This is what gives rise to those repeated cleansings so indispensable for the avoidance of accidents.

Condensation of Steam.—What is called the condensation of steam is its return to the liquid state. We have already seen that a slight compression beyond its maximum of elastic force is sufficient to restore it to that state, either in part or in totality, according as the compression is momentary, or continued until the volume of fluid is reduced to that which it occupied when in the liquid form; of course, without any addition of heat. But in engines, it is not after this fashion, which is in reality *the liquefaction of steam*, that its destruction is effected.

Condensation consists in *cooling* the steam by means of a certain quantity of cold water that takes up the heat that maintained it in the condition of an elastic fluid, yielding as result an amount of warm water, the steam from which has an elastic force very considerably less than that which has been destroyed, and may be rendered as feeble as can be desired, according to the volume and temperature of the cold water added.

This property of condensation is of the highest importance, since it enables us to get rid, almost instantaneously, of the potent fluid that has just produced an effect, but would afterwards neutralize it if allowed to retain its expansive properties. The only thing needed to render atmospheric air and other gases motive agents susceptible of replacing steam with advantage, is the capability of easy condensation, since they exist naturally in the state of elastic fluids under the ordinary temperature.

It will be shown shortly how powerful engines have been constructed, with the atmospheric pressure for motive agent, and using steam as an auxiliary power, but one possessing the valuable property of being destroyed, leaving a vacuum wherein the surrounding atmosphere can act with irresistible force.

Absorption.—We will conclude this outline of the phenomenon of condensation by citing an

experiment known to physicists under the name of *absorption*, designed, in the first place, to demonstrate the faculty we possess of creating a vacuum by means of the condensation of steam; and, in the next, to caution us against the accidents that may result from that selfsame property.

In chemical experiments, and in many industrial operations, an apparatus is used analogous in arrangement to that represented in Fig. 855. This arrangement consists of a closed receiver A, placed over a furnace B, and containing a liquid that has to boil; then a pipe D that starts from the receiver and, descending, plunges into a vessel C, containing some cold liquid, such as water, through which the steam disengaged from the receiver A has to pass.

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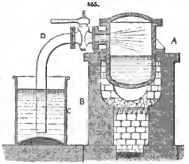

As soon as ever the ebullition commences, the steam that is generated expels, by degrees, the air contained in the apparatus, and forces it to escape by the pipe D, driving the liquid before it, whose level is necessarily the same in the tube and in the vessel; and finally passes through the tube itself, rising, in the form of bubbles, through the water contained in the open vessel. The air being completely expelled, the apparatus is now filled with steam only. Things being in this state, if we extinguish the fire and continue to keep a free communication between the two vessels through the pipe D, the steam will gradually cool, losing a portion of its elastic force. But, as that elastic force was the only thing that balanced the atmospheric pressure plus that of the height of the water in the vessel C, the excess of that external pressure begins to manifest itself by the rising of the water in the pipe D. As the cooling goes on, the pressure of the steam continues to diminish and the water to ascend in the tube till it reaches the top and finally penetrates the body of steam still remaining in the boiler A. At this juncture the whole of the steam is soon completely destroyed and a vacuum is created, that is to say, an absence of all expansible fluid. We then see the water continue rising, but this time with impetuosity, until the entire apparatus is filled, if the water in the vessel C be sufficient for the purpose.

This effect, so simple to understand, is produced every time that a capacity containing steam is placed in communication with a reservoir of liquid with a sufficient pressure, and that the steam is destroyed by condensation—on condition, however, that the pressure of the column of water in the tube, if full, exceed not that supported by the liquid in the open vessel. In the foregoing experiment it is certain that if the distance between the level of the water in the vase C and the horizontal portion of the pipe D had exceeded, vertically, ten mètres, the water in the reservoir could never have entered the boiler, and the vacuum would have remained.

Therefore, if absorption is a thing to be feared, a vacuum is not less so, since the atmospheric pressure, that has the power of raising the water from the lower to the upper reservoir, may likewise burst in the latter, if it be exhausted and have not sufficient strength of resistance. Whenever there is danger of such an accident occurring, it is remedied by means of a small valve, opening inwards, which allows the air to re-enter the apparatus. To prevent absorption, a cock E may be employed, which should be closed before the condensation of the steam.

We see, then, that the condensation of steam is the means of creating a vacuum and raising almost any volume of liquid to a height corresponding to the atmospheric pressure, and which varies according to the density of the liquid used. Effectually, what we have been signalizing as accidents, constitute, in many cases, most valuable resources in their practical application.

Calorific Action in the Formation of Steam.—Caloric, or heat, is the chief agent, or, to express ourselves more appropriately, the sole apparent cause of the phenomena of dilatation and the change of state that bodies undergo; for, by penetrating the mass of constitutive molecules, it compels them to separate, and widens the interstices that seem naturally to exist between them. This external fact might be defined by saying that heat repulses the molecules of a body from each other in order to make room for itself, and establish an equilibrium between its own intensity and that of the medium or space occupied by the mass of the body; and that the result of this intervention is an effort of repulsion equal and opposed to the cohesive force of the molecules themselves.

We conclude, from this definition as well as from the observed fact, that the greater the amount of heat so much greater is the effect of repulsion. Finally, this distension of the molecules by an excessive quantity of heat, after producing simple expansion or augmentation of volume, results in a change of state; that is to say, that from solid a body becomes liquid, and from liquid it passes into the gaseous state or steam.

It must not, however, be supposed, because this second change, as regards liquids, takes place in vacuum without any apparent intervention of heat, that that intervention is wanting. It would be an error. The action of caloric is quite as real as in any other mode of forming steam; and, as we have already remarked, the only result of a vacuum is to give rise instantaneously to what would have taken place but slowly in the open air. The atmospheric pressure is simply an effort to be overcome by larger quantities of heat in order to create steam beneath its influence. As to the heat necessary to produce the phenomenon in a barometer, it is taken from the liquid mass and from the instrument itself, instead of being supplied by fire.

There is, therefore, no exception as regards the formation of steam. Whatever method we make use of in order to produce it, caloric always intervenes, and with the same intensity, when the tensions are the same.

We only repeat here what has already been fully demonstrated in the preceding sections. We now pass on to the

Mechanical Power of Steam.—The reason why steam is used, in preference to permanent gases, to produce motive labour, is because of the facilities we have of quickly destroying its power; or, in general, of giving it a tension superior to that of the medium in which the motor works to which it is applied. For, the action of expansion being the same in all cases, such gases could be employed as motive force just as well as steam were it equally possible to increase or lessen their pressure without expenditure of mechanical force.

It is true that engines have been constructed worked by atmospheric air heated; such a process is quite practicable; but, besides the question of economy, it is much more difficult to deprive air of its heat after doing its work than it is to destroy steam by condensation. So that, up to the present, the latter remains master of the field. We shall now endeavour, therefore, to explain the mechanical properties of steam, as applied to motion, observing, at the same time, that the identical reasoning holds good in the case of any permanent gas.

Work Done with Full Pressure.—It has been seen that, when steam is let off from a receiver or reservoir of any kind, it escapes with an energy the intensity of which depends upon its own tension and that of the medium in which the flow takes place. The escape is, indeed, the consequence of the pressure exerted by the steam upon all points of the receiver containing it, and particularly upon the parts surrounding the orifice.

In order to transform this property into motive labour, let us suppose the following experiment: A vessel, A, Fig. 856, full of steam that can be continuously renewed with a tension greater than that of the ambient medium, is furnished with a vertical tube B of indefinite length. The latter contains a column of mercury resting upon a small piston *a*, while a stop-cock C enables the communication between it and the reservoir to be cut off.

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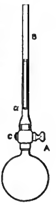

When the stop-cock is closed, the column of mercury and its piston or diaphragm are at the lower end of the tube, and rest upon the cock; but, if we come to open this last, the pressure of the steam will exert itself beneath the mercury and endeavour to raise it in order to make its escape. The result of this action will be different, however, according to the reciprocal situation of the elements.

In the first place, if the column of mercury, together with the external pressure which it has to bear, be equal or superior to the pressure exerted by the steam at its base, the column of mercury will remain stationary, and there will be no escape of steam; the mercurial column fully representing the resistance opposed to the expansion of the steam by the sides of the vessel.

But if the pressure of the steam be the greater of the two, the column of mercury will rise in the tube with an acceleration uniformly increasing till it becomes equal to that of the steam, beyond which it evidently cannot go.

Consequently, by choosing this point of uniform velocity, we have not only the representation, but the actual measurement of a certain mechanical work performed, for we have a weight—that of the column of mercury—raised and moving with a fixed velocity in a unity of time. Thus the simple pressure of the steam is transformed into a real dynamical effect. Now it is not at all necessary to suppose that the steam has acquired the full velocity due to its tension, for it may raise the weight with a uniform velocity as slow as can possibly be imagined. To conceive this, let us examine what would occur in the case under consideration.

In the first place, the column of mercury, being inferior in weight to the pressure of the steam, will rise with an increasing acceleration, whose more or less rapid progression will depend upon the greater or less excess of the power over the resistance.

But, if we re-establish the equilibrium at any given point of that progression by the addition of a small quantity of mercury, the acceleration will cease, and the velocity will preserve the uniform value it had at the moment of that re-establishment.

From this observation we may say, as in the case of hydraulic motors, that

In an engine, whose motion is uniform, the moving forces and the resistances are in perfect equilibrium.

The same experiment shows, likewise, the excess of force expended to overcome the inertia of a body, and make it acquire a uniform velocity in a given time.

To sum up the foregoing definition, the work done by steam is also measured by a weight, in kilogrammes, moving in a straight line at the rate of a certain uniform velocity, expressed in mètres, in a second of time.

The above experiment furnishes us, then, with the exact terms of the problem, wherein the weight of mercury raised, plus the ambient pressure it supports, represents the resistance overcome, and which must be equal to the pressure of the steam at the base of the column at the moment that uniform velocity takes place.

Therefore, if that column weighs, atmospheric pressure included, 2 kilogrammes, for instance, with an area at the base equal to 1 centimètre, the tension of the steam will have to acquire a similar value for every square centimètre, or, at an approximation, a pressure of about 2 atmospheres.

If the velocity, remaining uniform, were equal to 1 mètre in every second of time, the labour expended would be 2 kilogrammètres. The useful work would be half that quantity, because we suppose the atmospheric pressure to form half the resistance.

Not only is the work done by the effort exerted by steam assimilative to the simple displacement of a weight, but the quantities of steam to be expended may also be measured by the amount of work of which they are capable. In the preceding experiment it is clear that for every mètre which the resistance has been made to travel, a fresh volume of steam, measured by

the section of the tube and that distance, has had to be supplied by the reservoir. Consequently, the volumes of steam expended are exactly proportional to the work done, which itself is expressed by the distance and the intensity of the weight raised, while this latter, again, is represented by the inferior section of the tube and the pressure of the steam thereon. But, on the other hand, as the pressure depends upon the tension of the steam and the area of the section, we conclude that the volume of steam expended to do a given work is inversely proportional to the figure of its unity of effective tension.

Finally, 1 kilogrammètre being the product of 1 kilogramme by 1 mètre, corresponds to an expenditure of steam, with an effective tension of 1 atmosphere, equal to a column 1 mètre in height by 1 centimètre square at the base, barring a fraction: or 0·1 litre. If the effective tension were double, the volume would be one-half less, and so on.

Consequently, the expression for calculating the dynamical unity of volume of steam may be written thus:

$$V = \frac{0 \cdot 1\, k}{1^{k} \cdot 0333\, P} = \frac{k}{10^{k} \cdot 0333\, P};$$

wherein V represents, in litres, the volume of steam expended;
k „ the quantity of work, expressed in kilogrammètres;
P „ the effective pressure of the steam, that is to say, its excess over that of the medium opposed as resistance, knowing that 1 atmosphere corresponds to an exact pressure of 1·0333 kilogramme on the square centimètre.

Example.—What volume of steam would have to be expended in one second in order to produce 1000 kilogrammètres of work, its effective pressure being equal to 3 atmospheres?

Solution.—We find

$$V = \frac{1000}{10^{k} \cdot 333 \times 3} = 32 \cdot 259 \text{ litres.}$$

It is evidently the same with this value as with that which corresponded to the quantity of steam generated for every kilogramme of fuel; it is the theoretical value, or that which answers to the real useful effect; but in practice it varies very much, as we shall see presently, independently even of the method of using steam with expansion. It serves, however, as a general starting-point, which we must not lose sight of.

To show that this result is in conformity with the disposition of the Table that will be seen further on, we will ascertain in a direct manner what amount of work a given volume of steam with a known pressure is able to produce.

By adopting the cubic mètre for unity, it will suffice us to suppose that the base of the tube, in the preceding experiment, has an area of 1 square mètre; this will give 1 cubic mètre of steam generated for every mètre of distance travelled by the resistance. But, as this latter is always in equilibrium with the pressure of the steam, the weight raised will be precisely equal to the tension of the steam multiplied by the base. We shall therefore have 10333 kilogrammes for each atmosphere of pressure, multiplied by 1 mètre; that is, 10333 kilogrammètres as the theoretical work, developed by 1 cubic mètre of steam for every atmosphere of effective pressure.

We must once more observe that this result supposes, as a matter of course, that the initial pressure of the steam remains unaltered during the whole of the time that the work is being done; which is not the case when it is used with expansion, as we shall endeavour presently to explain.

Work Developed by Expansion.—From the physical properties recognized in vapours and gases in general, from the beginning, it may readily be imagined what takes place when any space, filled with a definite volume of steam, is enlarged. The said steam, by virtue of its unlimited power of expansion, which makes it tend constantly to augment its dimensions, continues filling the capacity it occupied, in spite of the extension of the latter, and exerting against the sides of the vessel a pressure that diminishes in the inverse ratio of the successive volumes it is made to assume.

This property, the effect of which is entirely analogous to the unbending of a spring that has been compressed and then suddenly allowed to go, is characterized in practice as *the expansion of steam*; and this designation is reserved for engines where steam is used upon that principle.

To convey a general idea of the use of steam with expansion, we need only revert to the experiment last cited, and suppose that the uniform velocity having been obtained, the stop-cock C, Fig. 856, is completely closed, so as to prevent the reservoir furnishing any fresh quantities of steam. That velocity will then be limited to the volume confined in the tube between the stop-cock and the base of the column of mercury raised; if the resistance remained fixed, the motion would be continued for a few moments by virtue of the acquired velocity, but with a uniformly retarded movement, till it became extinct, when the column of mercury would immediately fall, reducing the volume of steam to that which it occupied at the time that the stop-cock was closed.

But, if it were possible gradually to diminish the weight of the mercurial column in the same ratio as the pressure of the steam, which lessens as the space it occupies enlarges, the uniform ascending motion would be maintained, and the steam would still yield work through the agency of its expansive power, weaker and weaker, it is true, but which—were it not for the limit marked by the external resistance of the ambient medium, to which the force of the steam must be superior in order to produce an effect—might be indefinite.

Consequently, over and above the work developed by the free flow of steam from the reservoir, and estimated in the manner already indicated, there is yet a further amount of labour capable of being produced without any extra expenditure of steam; it is, in fact, certain that, in order to draw the greatest possible profit from steam, it should not be relinquished until its pressure has become so weak as to be almost unfit for any useful work.

There now remains to be calculated what are the total quantities of work developed under these

conditions. This it will be easy to do as soon as we have said a few words touching the law discovered by Boyle, commonly called the law of Mariotte, to which we have hitherto only alluded.

Mariotte's Law.—When a definite volume of any permanent gas is subjected to different pressures, it is readily perceptible that it diminishes in volume as the pressure increases, and, reciprocally, that the former augments as the latter decreases.

Apart from this first result, which is evident and palpable, it has been ascertained that, the temperatures being equal, the volumes occupied are in a striking manner inversely proportional to the pressures exerted; whence we also naturally deduce that the densities are directly proportional to these same pressures.

This important physical law bears the name of the Abbot Mariotte, a French physicist. Boyle was the first to enunciate it. It has since been verified by the most competent men, such as Arago and Dulong, Faraday, Pouillet, Regnault, and others. These illustrious savants found that Boyle's law suffered some slight variations with certain gases and under considerable pressures; the differences that have been observed by the aid of very delicate operations are not, however, of a nature to disturb the ordinary practical results. We shall therefore admit this law, purely and simply, in order to study the effects of steam in the phenomenon of expansion, where it presents itself as a permanent gas occupying successively different volumes.

Before approaching this subject, let us sum up the law by its numerical representation and by an example.

If we designate by P, the pressure of a gas, or the expression of its elastic force for the unity of surface;
V, its corresponding volume;
d, its density;
and by P', V', and d', the same properties under other conditions;
we say $P : P' :: V' : V$; in other words, *the pressures are in the inverse ratio of the volumes.*

We next find $d : d' :: P : P'$ or $d : d' :: V' : V$, that is to say,

The densities are directly proportional to the pressures, or inversely proportional to the volumes.

Example.—If we reduce by $\frac{1}{5}$ the volume $V = 1$ cubic mètre of a gas, whose pressure $P = 0 \cdot 80$ mètre of mercury, and whose density $d = 0 \cdot 0012$, what will be the pressure and density P' and d' under the new volume V'?

Solution.—The above relations supply the following:

$$P' = \frac{P \times V}{V'}; \text{ and } d' = \frac{d \times V}{V'}.$$

But, according to the data, the value of the fresh volume is

$$V' = 1^{cm} \times \frac{4}{5} = 0^{cm} \cdot 8.$$

From this value we deduce the following ones for the pressure and density:

$$P' = \frac{0 \cdot 80 \times 1^{cm}}{0^{cm} \cdot 8} = 1^{m} \cdot 00 \text{ of mercury; and } d' = \frac{0 \cdot 0012 \times 1^{cm}}{0^{cm} \cdot 8} = 0 \cdot 0015.$$

This law is so simple, that the above indications will certainly suffice to make its application understood. Besides, the two foregoing proportions supply the elements of all the problems that might be proposed. We must only remind our readers that, in order that its application may be correct, it is necessary that the gas subjected to the change of volume shall retain its primitive temperature, otherwise effects of dilatation or contraction are produced that influence and modify individually the result, which is supposed to be due solely to the alteration of volume.

Calculation of the Total Work done by the Expansion of Steam.—Since the amount of work done is always expressed by the product of the pressure exerted and the distance travelled by the resistance in the unity of time, balancing that pressure, any quantity of work may then be graphically represented by a surface that can also be measured by the product of two numbers. Effectually, let us suppose a certain effort, expressed in kilogrammes, to be represented upon any given scale by a right line A B, Fig. 857, the divisions upon which indicate precisely so many kilogrammes; and that the distance travelled by the resistance in the unity of time, and under the influence of that effort, be represented by a horizontal line A D, whose divisions are so many mètres or fractions of mètres; it is clear that, by completing the rectangle A B C D, its surface will be the actual measurement of the work, since it is the product of the units in A B by those in A D.

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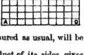

For instance, let A B measure 8 centimètres and represent 8 kilogrammes, while A D, measuring 10 centimètres, represents 10 mètres of distance travelled in the unit of time, say 1 second, the amount of work, measured as usual, will be $8 \times 10 = 80$ kilogrammètres.

But the surface of the rectangle, estimated, in like manner, by the product of its sides, gives also 80; so that each small rectangle formed by the intersection of the divisional lines represents 1 kilogrammètre.

This fact, very easy of comprehension, being once proved, let us suppose that during the journey the effort varies, though the velocity still remains uniform. It will then happen that the straight line A B, travelling from A B to D C, and which generated a rectangle by the fixity of its value, will no longer possess that fixity, and B C will consequently cease to be a straight line; neither will the figure be a rectangle, but a surface limited by right lines upon three of its sides, and by a broken or curved line upon the fourth; or again by a right line, but not parallel to

the base, if the variation in the resistance follows a certain regular law. We should thus obtain one of the three tracings indicated in the subjoined Fig. 858.

The total amount of work developed for each distance travelled A D, multiplied by the variable resistance, will, however, be none the less accurately represented by the surface of each figure. For such surfaces may be divided into sufficiently small parts, such as *a b c d*, in the direction of the distance travelled, for them to be considered as so many rectangles or portions of work generated by a particular effort which remains fixed during the corresponding time. The surface, then, of every one of those elementary parts will represent the amount of work answering to it; and as the sum of those parts is equivalent to the entire surface of the figure, it naturally follows that this last represents the total amount of work done.

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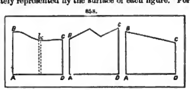

By knowing, then, the law of variation by which an effort is governed during the accomplishment of a certain labour, it will always be easy to reckon the total quantity of work developed, since the only thing required is to make a graphic representation thereof and to measure the surface of the figure thus obtained, according to units previously agreed upon as representatives of the efforts and the distance travelled.

The amount of work accomplished by steam during its expansion falls precisely within the conditions we have just examined. It is a decrescent effort exerted to overcome a resistance which is supposed to diminish in the same ratio in order that uniform velocity may be preserved. As to its law of decrescence, it is admitted that it follows that established by Boyle, as we have already stated, always supposing that the temperature of the steam remains unaltered during the period of expansion.

Let us endeavour, from this, to bring together these principles so as to find the value of the work that would be developed by a determinate volume of steam producing, at first, an amount of labour at full pressure and which can be measured as we have previously shown, and then expanding to a given limit.

By referring back to the experiment, page 424, which was admitted, we were enabled to ascertain the effect produced by a cubic mètre of steam acting with its full initial pressure, and we found that the work thus done was equal to 10333 kilogrammètres for every cubic mètre and for every atmosphere of effective pressure. Moreover, if the distance travelled be equal to 1 mètre, the corresponding pressure will be 10333 kilogrammes. If, now, this work being accomplished, no further steam be supplied, that already introduced and now isolated from its source will occupy gradually-increasing volumes, whence its pressure will successively diminish according to the same decrescent progression as that indicated by Boyle's law. The base of the receiver where the expansion takes place remaining the same, and the volume of steam, therefore, only *lengthening*, the decrescence will apply itself directly to the initial pressure of 10333 kilogrammes.

Let us, consequently, make a graphic representation of the work done at full pressure in the first place by a rectangle A B C D, Fig. 859, of which A B represents the initial pressure 10333, and A D the distance travelled during the performance of the work; then, having extended the base of the rectangle, let us draw lines parallel to A B from each of the points indicating the successive distances run from the moment that the steam was cut off. The value of every one of those vertical lines must be that of the pressure acquired at the end of the corresponding distances; and as these are exactly proportional to the successive volumes of the steam, and as the pressure acquired by the latter at every increase of volume is in the inverse ratio of the proportion which the last volume bears to the first, it will be easy to determine each fresh acquisition of pressure. At any rate, we get, from the preceding proportion, P : P′ :: V′ : V, the following, C D or A B : C′ D′ :: A D′ : A D.

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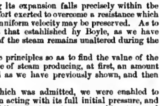


In other terms, if, for instance, each division of distance travelled or augmentation of volume be $\frac{1}{20}$ of the primitive one A D, we shall have as the successive values of the ordinates similar to C′ D,

$$\text{C D} \times \frac{20}{21}, \frac{20}{22}, \frac{20}{23}, \frac{20}{24}, \frac{20}{25}, \frac{20}{26}, \frac{20}{27}, \text{ and so on,}$$

because the consecutive volumes will be

$$\frac{21}{20}, \frac{22}{20}, \frac{23}{20}, \frac{24}{20}, \frac{25}{20}, \frac{26}{20}, \frac{27}{20}, \text{ and so on.}$$

By uniting, then, the extremities of all the ordinates thus determined, we obtain the complete figure A B C E F, whose surface will represent the total amount of work developed by the primitive volume of steam expanded, till it reaches the augmentation of volume indicated by the extension of the base A F of the figure, which may be continued to any required limit.

If we perform this operation with steam at the unity of pressure, the expansion being the same, the work found by squaring the figure will be proportional to any initial pressure which the steam may possess, because, when the expansion continues unaltered, the base A F is invariable and the heights are proportional to the pressures. But, if we take, as starting-point, a determinate volume of steam, it is clear that the result will likewise be in proportion thereto, because the base

A F is proportional to the primitive volume, and that, the heights being equal, the surface of the figure becomes proportional to its base.

Finally, we ascertain by this process the quantities of work that may be developed by a cubic mètre of steam at a pressure of 1 atmosphere with different degrees of expansion; and when it is wanted to find the work corresponding to another volume and another pressure, it is only necessary to make the product of those different data by the value indicated for 1 cubic mètre. The results thus obtained are completely satisfactory in practice. Only it is indispensable that the apparatus wherein the expansion takes place be so disposed that any external cooling may be avoided, otherwise there would ensue a condensation of the expanded steam that would render the application of Boyle's law incorrect.

Poncelet, who was one of the first to make this theory known, has also calculated a Table giving the quadrature of the initial figure for different expansions, throughout a notable extent.

We here reproduce that Table, to which we shall refer every time we have to calculate the conditions of an engine working with expansion.

TABLE OF THE TOTAL QUANTITIES OF WORK DEVELOPED BY 1 CUBIC METRE OF STEAM UNDER DIFFERENT EXPANSIONS, AND WITH A PRESSURE OF 1 ATMOSPHERE.

Volume after Expansion.	Quantity of Work Corresponding.	Volume after Expansion.	Quantity of Work Corresponding.	Volume after Expansion.	Quantity of Work Corresponding.	Volume after Expansion.	Quantity of Work Corresponding.
c. m.	kgm.	c. m.	kgm.	c. m.	kgm.	c. m.	kgm.
1·00	10333	1·35	13434	2·80	20973	5·50	27949
1·01	10436	1·40	13810	2·90	21335	5·60	28135
1·02	10538	1·45	14173	3·00	21686	5·70	28318
1·03	10639	1·50	14523	3·10	22024	5·80	28498
1·04	10739	1·55	14862	3·20	22353	5·90	28674
1·05	10837	1·60	15190	3·30	22671	0·00	28848
1·06	10935	1·65	15508	3·40	22079	6·25	29270
1·07	11032	1·70	15816	3·50	23279	6·50	29675
1·08	11129	1·75	16116	3·60	23570	6·75	30065
1·09	11224	1·80	16407	3·70	23853	7·00	30441
1·10	11318	1·85	16690	3·80	24128	7·25	30804
1·11	11412	1·90	16966	3·90	24397	7·50	31154
1·12	11504	1·95	17234	4·00	24658	7·75	31493
1·13	11596	2·00	17496	4·10	24914	8·00	31820
1·14	11687	2·05	17751	4·20	25163	8·25	32139
1·15	11778	2·10	18000	4·30	25406	8·50	32447
1·16	11867	2·15	18243	4·40	25643	8·75	32747
1·17	11956	2·20	18481	4·50	25875	9·00	33038
1·18	12044	2·25	18713	4·60	26103	0·25	33321
1·19	12131	2·30	18940	4·70	26325	0·50	33597
1·20	12217	2·35	19162	4·80	26542	9·75	33865
1·21	12303	2·40	19380	4·90	26755	10·00	34127
1·22	12388	2·45	19593	5·00	26964	15·00	38317
1·23	12472	2·50	19802	5·10	27169	20·00	41289
1·24	12556	2·55	20006	5·20	27969	25·00	43505
1·25	12639	2·60	20207	5·30	27566	50·00	50758
1·30	13044	2·70	20597	5·40	27759	100·00	57920

Use of the preceding Table.—The first column of the above Table shows the successive volumes that a cubic mètre of steam may assume by expansion under a pressure of 1 atmosphere, and the second the total quantities of work corresponding thereto, developed before and during expansion. The Table exhibits, also, the great advantage of prolonged expansion.

So that a cubic mètre of steam that only develops 10333 kilogrammètres of work if used without expansion, produces 26964 kilogrammètres when allowed to expand to five times its primitive volume, and 34127 when the expansion is ten times that volume. Let us add that, in order to find the work corresponding to any particular volume and effective pressure, it is sufficient to form the product of those data by the number in the Table answering to the same expansion. For instance, if we want to know the amount of work done by $0^{c\,m}\cdot400$ of steam at a pressure of 5 atmospheres and an expansion of five times its volume, we have

$$26964 \times 0^{c\,m}\cdot400 \times 5 = 53928 \text{ kilogrammètres.}$$

The preceding notions are sufficient to convey a practical knowledge of the conditions that determine the existence of the agent that animates the motors now under consideration.

It was clearly necessary that we should first of all become acquainted with its physical properties, that is to say, the laws that govern its simple formation, and the natural phenomena which it presents, before even any application of it is made. The second point was to ascertain its mechanical power or the conversion of its mere physical pressure into work, characterized by a resistance overcome and a distance travelled.

Having demonstrated this, there can be no difficulty in the way of understanding the description and working of a steam-engine.

The amount of work developed through the expansion of steam may be readily found, with

mathematical accuracy, by the following Rule, since the dual logarithm of any given number can be calculated without the use of tables in a few minutes. See Byrne's 'Dual Arithmetic a New Art.'

To Find with Mathematical Accuracy the Elastic Force of Steam in Units of Work. Rule.—Multiply the pressure at which the steam is admitted by the distance travelled by the piston before the steam is cut off, which product call (A). Divide the whole length of the stroke by the above-mentioned distance, and add 100000000 to the dual logarithm of the quotient; call the sum (B). Then A multiplied by B gives the whole units of work when eight decimal places are cast off for the dual logarithm.

Suppose the pressure of the steam = 21 lbs., the length of stroke 12 ft., and the steam cut off at 4 ft.

$$4 \times 21 = 84\text{; call (A).} \qquad \frac{12}{4} = 3. \quad \text{Dual logarithm of } 3\cdot = \begin{array}{r} 109861229, \\ 100000000, \\ \hline 2\cdot 09861229, \text{ (B).} \end{array}$$

A × B = 2·09861229 × 84 = 176·28343236, the exact area of the figure A B C E F, Fig. 859. Hence, the rule gives 176·28 units of work done on each square inch of piston in a stroke.

In practice the *Indicator* gives a very different figure: however, the nearer the Indicator-diagram approaches the true or mathematical diagram, the more perfect is the working of the engine.

Suppose the pressure of steam to be taken at 48 lbs.; length of stroke = 5 ft., and the steam cut off at 2 ft. In this case 48 × 2 = 96, which call (A).

$$\tfrac{5}{2} = 2\cdot 5 \text{ dual logarithm of } 2\cdot 5 = \begin{array}{r} 91629073, \\ 100000000, \\ \hline 1\cdot 91629073, \text{ (B).} \end{array}$$

A × B = 1·91629073 × 96 = 183·96391008, which is mathematically correct. Therefore the rule gives 184 units of work on the square inch in a single stroke.

Ques.—Steam of 42·35 lbs. pressure is admitted to the cylinder for 2·36 ft. of a stroke of 10·45 ft., then being cut off acts expansively; how many units of work is done on 1 sq. in. of piston in a single stroke?

$42\cdot 35 \times 2\cdot 36 = 99\cdot 946$ (A). $\dfrac{10\cdot 45}{2\cdot 36} = 4\cdot 428.$ Dual logarithm of which may be calculated in a few minutes.

$$\text{Dual logarithm of } 4\cdot 428 = \begin{array}{r} 148794803, \\ 100000000, \\ \hline 2\cdot 48794803, \text{ (B).} \end{array}$$

A × B = 99·946 × 2·48794803 = 248·66045380638. Eight decimals being allowed for the dual logarithm 2·48794803, 99·946 × 2·4879 = 248·66 the units of work done on a square inch of piston in a stroke.

Ques.—The length of the stroke in a condensing-engine is 12·3 ft., the pressure of the steam 43·7 lbs., and the steam cut off 3·7 ft. of the stroke. Find the gross load upon each square inch, and the point at which the velocity of the piston is greatest?

$$\frac{12\cdot 3}{3\cdot 7} = 3\cdot 324327.$$

The dual logarithm of 3·324327 may be calculated in a minute or two; it is = 120126729, which, when divided by 10^8, = 1·20126729. In the language of dual arithmetic, this operation is concisely expressed thus:

$$\frac{\downarrow,\left(\dfrac{12\cdot 3}{3\cdot 7}\right)}{10^8} = 1\cdot 20126729.$$

The amount of work on 1 sq. in. of piston in a single stroke =

$$43\cdot 7 \times 3\cdot 7 \times 1\cdot 2013 + 43\cdot 7 \times 3\cdot 7 = 43\cdot 7 \times 3\cdot 7 \times (2\cdot 2013) = 355\cdot 928197.$$

Hence, the mean pressure on the square inch $= \dfrac{355\cdot 928197}{12\cdot 3} = 28\cdot 94$ lbs.

It is evident that the velocity is greatest at that point of the stroke where the expended steam attains the pressure of 28·94 lbs. Then, putting x for this point in the stroke, we have, by Boyle's law, $28\cdot 94 : 43\cdot 7 :: 3\cdot 7 : x \quad \therefore \quad x = 5\cdot 59$. It is further evident that the length of the stroke, 12·3 divided by 2·20126729, gives the points x also.

Ques.—The length of stroke = 9·76 ft., pressure of steam = 45·3 lbs., steam cut off at 2·5 ft. of the stroke, the area of the piston = 4185·39 sq. in., the weight moved having the same motion as the piston = 72640 lbs.; what will be the maximum velocity of the piston?

$$\frac{9\cdot 76}{2\cdot 5} = 3\cdot 904.$$

The dual logarithm of 3·904 divided by 10^8 = 1·37200166; then, according to what has been shown in the last example, $\dfrac{9\cdot 76}{2\cdot 37200166} = 4\cdot 115$ ft., the length of stroke made when the velocity is greatest. The work of the steam up to this point, on the whole piston, =

$$45\cdot 3 \times 2\cdot 5 \times (1\cdot 49834708) \times 4185\cdot 39 \times 72640.$$

Since the dual logarithm of $\frac{4\cdot 115}{2\cdot 5}$, written $\downarrow,(1\cdot 646)$ divided by $10^8 = \cdot 49834708$, to which 1 is added. The units of work by the whole piston in a single stroke =

$$45\cdot 3 \times 2\cdot 5\,(2\cdot 372) \times 4185\cdot 39 = 1124317.$$

For $2\cdot 372 = \downarrow,(3\cdot 904)$ divided by $10^8 + 1$. $\therefore$ Mean pressure on the square inch =

$$\frac{45\cdot 3 \times 2\cdot 5 \times 2\cdot 372}{9\cdot 76} = 27\cdot 52 \text{ lbs.}$$

But the work done upon the resistances up to the point $(4\cdot 115)$ of the stroke where the velocity is a maximum $= 4\cdot 115 \times 27\cdot 52 \times 4185\cdot 39 = 473974$ units of work. $\therefore$ The accumulated work in the piston when the velocity is a maximum $= 710210 - 473974 = 236236$. Then, putting v for the maximum velocity of the piston in feet a second, $\frac{v^2 \times 72640}{64\frac{1}{3}} = 236236$ $\therefore$ $v = 14\cdot 464$ ft.

Ques.—Taking the data of the last example, find the weight (W) of the mass moved, supposed to be posited in a position to have the same motion as the piston when its maximum velocity is 5 ft. a second?

W may be found from knowing that $\frac{5^2 \times W}{64\frac{1}{3}} = 236236$. $\therefore$ W = 639713 lbs. = 286 tons nearly.

Ques.—The length of the stroke in a condensing-engine = 10 ft., the pressure of the steam = 30 lbs., the steam cut off at 2 ft. of the stroke, the area of the piston 4000 sq. in., and the weight of the mass moved having the same motion as the piston = 50000 lbs.; what is the velocity of the piston when 4 ft. of the stroke is made, supposing all the appliances to be perfect?

Total work on 1 sq. in. of the piston $= 30 \times 2 \times (2\cdot 60943791) = 156\cdot 566$. For the dual logarithm of $\frac{10}{2} = 160943791$, and 1 added to 160943791, divided by 10^8, gives $2\cdot 60943791$. The mean pressure of the steam, or gross load, $= \frac{156\cdot 566}{10} = 15\cdot 657$ lbs. The work done on the piston when 4 ft. of the stroke is made $= 4000 \times 30 \times 2 \times (1\cdot 69314718) = 406355$. Since the dual logarithm of $\frac{4}{2} = 2, = 69314718$. But the excess of this work over the work expended in moving the resistance shows the units of work accumulated in the piston when 4 ft. of the stroke is made. Work of resistance up to this point of the stroke $= 15\cdot 657 \times 4000 \times 4 = 250512$. $\therefore$ Work accumulated in the piston $= 406355 - 250512 = 155843$. v being put for the velocity, then $\frac{v^2 \times 50000}{64\frac{1}{3}} = 155843$. $\therefore$ $v = 14\cdot 16$ ft.

In the same manner the velocity may be found for any part of the stroke. The weight of the mass moved in any engine, referred to the piston, may be found as in an example previously given. The mechanical principles of steam evolved in the last four examples are worthy of particular attention.

Before the art and science of dual arithmetic was discovered, independent and direct solutions of such questions as the following defied the combined skill of mathematicians. In such cases results were generally guessed at, or roughly approximated to, by the help of empirical rules and limited tables. Questions that presented great difficulties may now be solved with ease, and without extraneous aids or methods of approximation; the subject is merely touched upon in this place to call forth a spirit of inquiry respecting an art so easily acquired, and at the same time so extensive in its application.

Ques.—Steam at 60 lbs. pressure (p) is cut off at x feet of the stroke, and expands, according to Boyle's law, so that the mean pressure throughout the stroke = 32 lbs. (q), the whole stroke = $7\cdot 5$ ft. (a); find x by a direct process, without the use of tables or empirical rules?

We have before shown that $\downarrow,\left(\frac{a}{x}\right)$ is read the dual logarithm of $\frac{a}{x}$, which any student may calculate by common addition and subtraction.

$$\text{Then } \frac{p\,x\left(\frac{\downarrow,\left(\frac{a}{x}\right)}{10^8} + 1\right)}{a} = q. \qquad \therefore\ x\downarrow,\left(\frac{a}{x}\right) + 10^8 x = 10^8\,\frac{a\,q}{p}.$$

$$\therefore\ x\downarrow, a, - x\downarrow,(x) + 10^8 x = 10^8\,\frac{a\,q}{p}. \qquad \therefore\ x\,(\downarrow, a, + 10^8) - 10^8\,\frac{a\,q}{p} = x\downarrow,(x).$$

Putting M for $10^8\,\frac{a\,q}{p}$, and N for $\downarrow, a + 10^8$; the last equation may become $x\,\text{N} - \text{M} = x\downarrow,(x)$.

Then a natural number n may be found of which N is the dual logarithm; and a natural number m of which M is the dual logarithm.

$$\therefore\ \frac{n^x}{m} = x^x. \qquad \therefore\ \frac{1}{m} = \frac{x^x}{n^x} = \left(\frac{x}{n}\right)^x.$$

Taking the $\frac{1}{n}$ root of both sides of the last equation, and substituting z for $\frac{x}{n}$, then,

$$\left(\frac{1}{m}\right)^{\frac{1}{n}} = \left(\frac{x}{n}\right)^{\frac{x}{n}} = z^z. \qquad 10^8\,\frac{7\cdot5 \times 32}{60} = 400000000, = \downarrow,(m).$$

$$\therefore\ \downarrow,\left(\frac{1}{m}\right) = {}'400000000;\ \downarrow,(7\cdot5) = 201490302.$$

$$\therefore\ \downarrow,(7\cdot5) + 10^8 = \downarrow,(n) = 301490302,\ \downarrow,\left(\frac{1}{n}\right) = {}'301490302. \qquad \therefore\ \frac{1}{n} = \cdot049050593.$$

$$\text{Then } \downarrow,\left(\frac{1}{m}\right)^{\frac{1}{n}} = z\downarrow,(z) = {}'400000000\,(\cdot049050593) = {}'19622037.$$

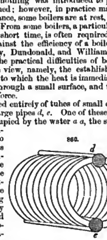
The general solution of equations of the form $z^z = b$, or $z \downarrow, (z) = {}'19620237$, is given in 'Dual Arithmetic a New Art,' by Oliver Byrne, Part II., page 98. By this new art z is readily found to be = the dual number $\frac{1}{10}\downarrow$ '3 4, 5,'2 '4 '6 '6 '0, which is equal to the natural number ·076221291.

$$z = \frac{x}{n} = (\cdot049050598)\,x = \cdot076221291. \qquad \therefore\ x = 1\cdot53932 \text{ feet.}$$

We have now pointed out how heat, water, and steam, brought together in a boiler, combine to produce mechanical effect; but the appliances and experiments which we have thus far advanced were favourable, so that nothing was introduced to prevent the results predicated by abstract reasoning from being obtained; however, in practice many things conspire to curtail the mechanical effect of steam; for instance, some boilers are at rest, others in motion, while the motor steam is being generated in them. From some boilers, a particular pressure and a constant supply of steam from a limited space, in a short time, is often required. The fuel employed and water used play important parts for or against the efficiency of a boiler. The original boiler arrangements of James, Ogle, Montgomery, Dundonald, and Williams, and of a few other ingenious inventors, have overcome many of the practical difficulties of boiler construction. Two methods are employed to effect the object in view, namely, the establishment of a large heating-surface compared with the volume of water to which the heat is immediately applied, and the application of considerable heat to the water, through a small surface, and thus rapidly effect the conversion of water into steam of the required force.

W. H. James' boiler was composed entirely of tubes of small diameter arranged side by side, as in Fig. 860, and inserted into two large pipes *d*, *e*. One of these tubes or rings is shown in section, Fig. 861, and exhibits the space occupied by the water *a a*, the steam room *b b*, the horizontal pipe *d* serving for a steam-pipe, the feed-pipe *e* which distributes the water into the rings uniformly. The thickness of the rings was $\frac{1}{16}$ in., of the horizontal pipes *d* and *e* $\frac{1}{4}$ in., and the diameter of the boiler 24 in. The fire was placed on a grate near the bottom, and sometimes directly on the tubes, which thus formed the grating itself. This boiler was enclosed by brick-work, from inside the arched roof of which much heat was economized by reverberation. James patented this boiler in 1825, and he may be considered to be the first inventor who practically understood what was required to constitute an efficient boiler. The comparative merits of the boilers specified in the succeeding tabulated arrangement can, in a great measure, be comprehended from the appended data and registered results.

860.



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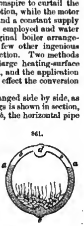


The boiler invented by Nathaniel Ogle is shown in Figs. 862, 863, 864.

Fig. 862 shows a vertical section of Ogle's boiler, Fig. 863 is a ground plan, and Fig. 864 section of the top.

a, *a*, *a*, are tubes or vessels placed over the furnace B in an upright or perpendicular or vertical position. *c*, *c*, are tubes or pipes for connecting the tubes *a*, *a*, *a*, together. *d*, *d*, *d*, are the inner flues which run through the inside of the tubes or vessels *a*, *a*, *a*, and out at the top, and which flues or tubes are also placed in an upright or perpendicular or vertical position, and are for the escape of the heated air or gas arising from the fire, which may be made on the furnace bars *e*, or in any other way that may be found convenient. *f*, *f*, *f*, are flues or spaces which also serve for the escape of the heated air or gas arising from the fire. *g*, *g*, are the sides of the furnace; the front is supposed to be taken away, in order to show the boiler or generator. *h*, the chimney. *i*, *i*, *i*, are bolts for screwing the tubes or pipes *c*, *c*, together. *k*, the feed-pipe for supplying the boiler or generator with water. *l*, the steam-pipe. *m*, *m*, *m*, are tubes or pipes to connect the tubes or pipes *c*, *c*, together. *n* is the ash-pit. The water which is contained between the tubes or vessels *a*, *a*, *a*, may be pumped into the boiler or generator to any height at which it may be found most convenient, and a safety-valve may be attached in the usual way.

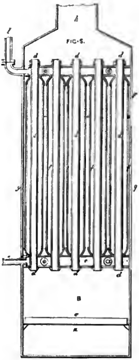
From a series of well-directed experiments, Ogle brought his boiler to a great state of perfection; he received much practical assistance from Thomas Don, the experienced millwright and engineer, who for a considerable time was engaged with Ogle in carrying out steam locomotion on common roads. One of the last arrangements given to Ogle's boiler is shown in Fig. 865; one of the horizontal tubes, detached, is shown in Fig. 866; the dimensions, shown at A, 3 by $3\frac{3}{4}$ in.; length, 3 ft. 4 in.

This boiler was composed of eleven rows of perpendicular tubes, ten tubes in each row; the internal diameter of the upright tubes was 3 in.

After a series of experiments, Ogle and Don so proportioned the heating-surface to the volume

Inventors.	Number of Tubes.	Diameter of Tubes.	Length of Tubes.	Superficial Area acted on by Fire.	Cubic Contents of Water and Steam.	Proportion of Area to Contents of galls. Heated by Number of Feet.	Diameter and Number of Cylinders.	Length of Stroke.	Remarks.
James, boiler in the coach at Epping Forest.	136	1 in.	2 ft. 3 in.	125 ft.	4155 cub in. 16 galls.	8·2	2 cylinders, 3½ in. area, united area, 19·2.	12 in.	Coach, driven at great speed, 2 tons, and 26 passengers.
1825.									
James, boat boilers at Vauxhall.	272	1¼ in.	4 ft.	363 ft.	19384 cub. in. 70 galls.	7·0	2 cylinders, 6 in. diam., 36·2.	18 in.	Drove a boat on the Thames 6 miles an hour against tide.
James, coach at Vauxhall.	280	⅝ in.	2 ft.	107½ ft.	4099 cub. in. 14 galls.	6·7	4 cylinders, 2 in. diam.	12 in.	Drove coach 12 miles an hour, weight 2 tons, 6 passengers, and a drag
James, 30 H.P., Birmingham, 3 cellular plates.	57 cells.	2 in.	10 ft.	240 ft.	21204 cub. in. 76½ galls.	3·1	3 ft.	8 ft.	Drove 30 H.P. with less fuel and less fire-surface, but was obliged to add more steam room as recipient for low pressure.
James, 4 H.P., to drive factory engine at Vauxhall.	50	1 in.	2 ft. 8 in.	6975 sq. in. 48½ ft.	1756 cub. in. 6½ galls.	7·7	3½ in. diam. 8·8 area.	1 ft.	Drove lathes at Vauxhall, and proved with 2 pumps and by proof bar to 4 H.P., steam 200 lbs. to the inch.
James, at Salt's Birmingham driving factory.	1 cellular plate 7 × 3, and 6 in. deep.	8 in. deep. 4 in. of water.	7 ft. long.	42 ft.	16144 cub. in. 65 galls.	0·63	1 cylinder, 6 in. diam., 70 lbs. steam.	12 in.	Drove 16 lathes for brass turner = 4 H.P., 76 to 90 strokes a minute, 2½ cwt. slack a day.
Ogle	144 within.	4 in.	3 ft. 8 in.	788 ft.	48818 cub. in. 178 galls.	4·4	2 cylinders, 11½ in. diam.	16 in.	Weighed from 4 to 6 tons, carried 14 passengers at about 10 to 12 miles an hour.
1830.									
Ogle, large coach	112	4 in. out. 1½ in. in.	20; 3 ft. 6 in. remainder 3 ft.	71082 sq. in. 486 ft.	47070 cub. in. 170 galls.	2·6	2 cylinders, 11½ in. diam.	16 in.	Drove coach weighing 8 tons at 16 miles an hour, wheels 5 ft. diam., steam 200 lbs.
Ogle, light coach	80	4 in. out. 1¼ in. inside.	16; 3 ft. 8 in. remainder 3 ft.	48800 sq. in. 338 ft.	33738 cub. in 122 galls.	2·7	2 cylinders, 7 in. diam.	16 in.	Weight of coach, 3½ tons, ran 18 miles an hour, 14 passengers.
Ogle, new boiler for the large coach.	133	3½ in. 6 in. the horizontal.	{ 110; 2 ft. 6 in. 20; 3 ft. 4 in. 3; 4 ft. 2 in. }	46306 sq. in. 320 ft.	50534 cub. in. 182½ galls.	1·2	11½ in. diam.	16 in.	
Hancock, steam coach ..	12 plates. 20 tubes.	2 ft. 6 in. × 3 ft.	.. ..	27216 sq. in. 188 ft. 315 ft.	19446 cub. in. 70 galls. 116 galls.	2·7	2 cylinders, 6 in. diam.	16 in.	Drove coach, 2½ tons, with 14 passengers and 3 engineers, average 8 miles an hour.
1827.									
Maceroni, steam coach ..	81	6 in. diam. 3½ in. diam.	24 in. 36 in.	41901 sq. in. 291 ft.	33290 cub. in. 127 galls.	2·2	.. ..	..	Coach at Paris ran very well.
Busk, 10-H.P. boiler ..	28	3½ in.	8 ft.	233 ft.	25536 cub. in. 92 galls.	2·4	.. ..	..	Evaporated 200 galls. an hour.
Perkins, boilers at Russell's.	88	2·4 in. inner. 3 in. outer.	18 in.	131 ft.	72 galls.	1·8	.. ..	..	10 H.P.
1822.									
Stephenson, railway coaches, 14 H.P.	108	1¼ in. 2 in.	.. ..	252 ft.	59371 cub. in. 214½ galls.	1·1	2 cylinders, 11 in. diam., 50 lbs.	17 in.	Evaporates nearly a cubic foot or 6·2 galls. a minute, 372 galls. an hour.
1815.									
Nash, boiler put up at Wormley, near Bristol.	.. .. ..	.. .. ..	.. ..	16777 sq. in. 116 ft.	38181 cub. in. 138 galls.	0·8	.. ..	..	8 H.P., burnt 4 cwt. of coals in 12 hours, driving 2-pr. stones, or 7 lbs. each H.P. an hour.
Long, American boiler, see 'Mechanic's Magazine,' vol. xx.	2 boilers, 6 ft. 8 in. 20 in. diam. 20 tubes in each.	.. .. ..	.. ..	36852 sq. in. 241 ft.	68498 cub. in. 211 galls.	0·8	.. ..	..	Evaporated 200 galls. an hour, 90 lbs. an inch, 2 bushels anthracite coal.
Hancock, boat 'Minerva,' 1837.	12 plates or chambers.	3 ft. 8 in. × 4 ft.	.. ..	49392 sq. in. 343 ft.	72578 cub. in. 262 galls.	1·3	2 cylinders, 14 in.	3 ft.	Drives the 'Minerva,' 1 condenser, 40 to 46 strokes a minute.
Marshall, 2 boilers.. ..	Flue boiler, 1 flue returning. Boiler, 2 ft. 2 in. diam., 16 ft. long. Fireplace, 2 ft. 1 in. diam., 4 ft. long. Flue, 20 ft. long, 1¼ ft. diam.		.. ..	15128 sq. in. 105 ft.	110808 cub. in. 400 galls.	0·26	14 in.	3 ft.	Hardly drove the boat with these two boilers; oscillating steam-engine, 35 strokes.

862.



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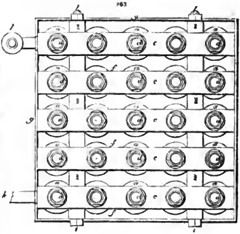

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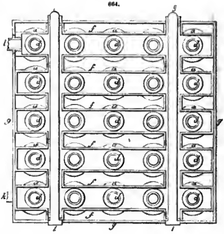

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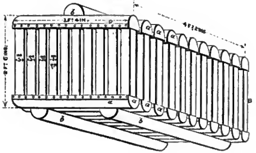
865.



of water to which it communicated a maximum calorific value, that they dispensed with the inner flues and ultimately produced a boiler of the type shown in Fig. 865. Ogle inserted a steam-pipe at *b*; this pipe was pierced with holes like that shown in the Thomson boiler, Fig. 835. The holes in Ogle's superheating and drying tube were not equidistant; they stood farther apart, near the exit at *b*. Ogle possessed great mechanical skill, as well as extensive general information; he was highly educated in both college and school. In early life he was an officer in the Royal Navy; his attainments in other departments of science and art were considerable, and no man possessed a heart with a greater amount of the milk of human kindness than Nathaniel Ogle. The writer knew him well; peace be to his ashes.

The boiler shown in Fig. 865 had

	sq. in.
110 upright tubes; surface of each was 351 sq. in.; in all	38,610
22 horizontal tubes *a, a, a*; surface each 320 sq. in.; in all	6,400
3 horizontal tubes to join the rows of tubes at top and bottom, for water-supply and to take off the steam; the surface, in all ..	1,296
Or 320 sup. ft. or heating-surface contained in a space of 34½ cub. ft.	46,306

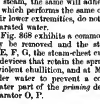
		cub. in.
Solid contents	Upright tubes, 288 cub. in.; in all	31,680
	Horizontal tubes	18,424
	Or 180 gallons.	50,104

The Dundonald boiler is shown in Figs. 867 to 871; this arrangement is original and very complete.

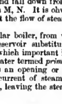
Fig. 867 is a general view of the boiler invented by Thomas Cochrane, commonly called Earl Dundonald. A is an aperture at the back of the ash-pit to admit heated air through a duct or channel B, C, to unite with the candent gaseous products of combustion at C, and complete the decomposition of fuliginous matter. From this boiler Dundonald cuts off the steam-chest D, E, F, G, reducing the altitude of the boiler to D, G, and in lieu of the steam-chest he adds a reservoir H, K, of sufficient capacity, using the device L, M, being a plate of iron or other substance, whereof the part M may either be immersed in the water, or a pipe or channel M, L, may be added, whereby the spray or water hurried up by the steam may descend, so that the steam which shall enter the centrifugal separator O, P, may be comparatively dry; but should any spray remain enveloped by the steam, the same will adhere to and fall down from the separator through the tube or channel Q, which performs the same office as M, N. It is obvious that these channels, being immersed at their lower extremities, do not permit the flow of steam in a direction contrary to the issue of the separated water.

Fig. 868 exhibits a common tubular boiler, from which the lofty appendage of a steam-chest may be removed and the steam reservoir substituted. H, K, represents that reservoir, and D, E, F, G, the steam-chest cut off, which important improvement Dundonald renders practicable by devices that retain the spray or water termed *priming*. L, M, is a guard to ward off the effect of violent ebullition, and at M, N, is an opening or channel (the lower part whereof terminates under water to prevent a counter-current of steam), through which opening or channel the greater part of the *priming* descends, leaving the steam comparatively dry to enter the centrifugal separator O, P.

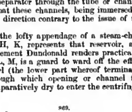
867.



868.



869.



870.

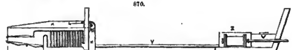


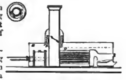
Fig. 869 is an enlarged view of that separator, on the sides of which the remaining spray impinges by its rectilinear impulse, and adheres until it descends through a submerged pipe or channel Q, and returns into the boiler. The dry steam enters the reservoir H, K, at the ends of the separator O, P, by the openings P, the rest O being closed. But in constructing boilers it is proposed wholly or partly to envelop the funnel in the reservoir, and so render the steam still more dry by imparting thereto the heat which the products of combustion may then and there be

able to impart. Condensed steam may be drawn off from the reservoir H, K, and returned to the boiler by a small transfer-pump R, or by a connection with the feed-pump, or it may be blown out through a pipe by the steam pressure.

Fig. 870 shows a means of communicating power to propelling apparatus without long shafts or the ordinary gear. *x* is a steam generator; *y* is a steam-pipe enclosed in a case composed of the least-conducting material to prevent loss of heat; and *z* is a steam reservoir, placed as near the extremity of the vessel as may be convenient; thus a short propeller-shaft from an engine contiguous thereto will suffice. Contiguous to the reservoir *z*, and reaching to the stern-frame, Dundonald placed a water or an air and water tight tank, through which the propeller-shaft passes, whereby the bearings were kept cool, and leakage from the stuffing-boxes prevented.

Fig. 871 is a boat boiler, which, as regards its steam-generating arrangements, may be on the usual locomotive plan. Dundonald's improvements consisted in placing around the funnel, or where most convenient, a steam-separator to ward off the effect of violent ebullition or external agitation, and draw off the spray or *priming* arising therefrom by the pipe or channel M, N, or Q, leaving the steam comparatively dry to pass into the lower reservoir H, K.

871.



Dundonald justly claims the constructing of boilers with steam reservoirs below the level of the water in lieu of and dispensing with steam-chests above; and also the means of retaining the heat and drying the steam in a reservoir by the presence of a portion of fire-surface, or by the passage of the flue or chimney therein.

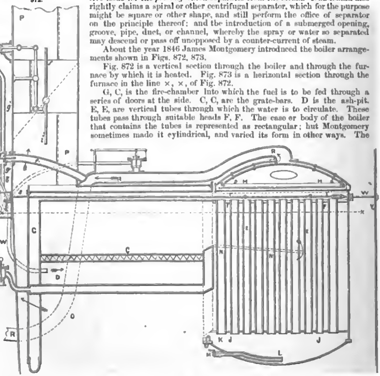
His invention also prevents the overflow of water, termed *priming*, into a steam reservoir by protecting plates or channels, having grooves or ducts, whose lower extremity is immersed in water within the boiler, or terminates in the steam reservoir, and so leaves a free issue for the *priming* which separates from the steam. Dundonald also rightly claims a spiral or other centrifugal separator, which for the purpose might be square or other shape, and still perform the office of separator on the principle thereof; and the introduction of a submerged opening, groove, pipe, duct, or channel, whereby the spray or water so separated may descend or pass off unopposed by a counter-current of steam.

About the year 1846 James Montgomery introduced the boiler arrangements shown in Figs. 872, 873.

Fig. 872 is a vertical section through the boiler and through the furnace by which it is heated. Fig. 873 is a horizontal section through the furnace in the line ×, ×, of Fig. 872.

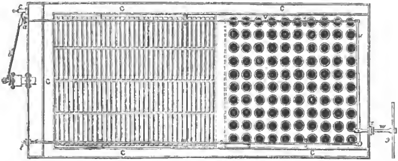
G, C, is the fire-chamber into which the fuel is to be fed through a series of doors at the side. C, C, are the grate-bars. D is the ash-pit. E, E, are vertical tubes through which the water is to circulate. These tubes pass through suitable heads F, F. The case or body of the boiler that contains the tubes is represented as rectangular; but Montgomery sometimes made it cylindrical, and varied its form in other ways. The fire-chamber is surrounded by a water-space G, G, which is continued on the sides of the containing case of the vertical tubes. H, H, is the steam-chamber; I, I, the water-line; J, J, that portion of the boiler that is below the lower tube-head; and K, K, the bottom of the boiler. This bottom is made convex outwards, and may be either spherical or conical; and as the heat from the fire does not act on this bottom, the water contained between it and the lower tube-head

872.



will be in a state of comparative quiescence, in consequence of which the sedimentary matter, from which incrustations are ordinarily formed on the bottoms and other parts of boilers, will settle down in a loose unaggregated state. By means of a tube L, and a cock M, or by the aid of an ordinary valve, the accumulated sediment may at any time be blown off without occasioning any considerable waste of water.

873.



The flame or heat from the fire-chamber is directed, first, against the upper ends of the vertical tubes, and then upon their lower ends; and to effect this I place a partition or diaphragm N, N, so as to divide the larger portion of the chamber containing the tubes into two parts, an upper and lower chamber. This will direct the draught, as indicated by the arrows, first into the space above the diaphragm, around which it will pass to the chamber below the diaphragm, thence into the flue-space O, O, below the ash-pit, and thence to the chimney P. The introduction of this diaphragm-plate is an important feature, and first introduced by Montgomery.

Q, Q, Fig. 872, is a shield, consisting of a plate of metal placed below the boiler-head at such distance therefrom as to allow of a steam passage between the two; its diameter is somewhat less than that of the boiler-head, so as to allow the steam from the steam-chamber to pass into it whilst it completely covers the upper ends of the vertical tubes. By this arrangement of the shield the steam is drawn equally from all parts of the circumference of the boiler; the foaming of the water when the pressure is taken off by the admittance of steam into the cylinder will also be in great measure prevented. R, R, is the steam-pipe leading from the middle of the boiler-head to the engine.

Montgomery adds:—"The producing of a free and continuous circulation of the water in a boiler has been frequently attempted, but has not been, as I am well assured, hitherto attained; but by my plan of arranging the respective parts of the boiler in such way as that its bottom shall not be subjected to the direct action of heat, and of introducing it laterally among the vertical tubes at their upper ends, I not only secure the ready depositing of the sediment as stated, but effect a rapid and decided circulation, which prevents all incrustation on the interior of the tubes and at the bottom of the boiler, and also augments the quantity of steam generated. I have represented the diaphragm as situated at about one-third of the height of the boiler from its top, but it may be placed near its middle, or lower down if preferred, the fire-chamber also being depressed to accord therewith."

The fire is to be ignited at the part nearest to the boiler, and successively through the doors more and more distant from it, the object of which is always to keep a clear fire towards the boiler, the fireman moving the fuel which has ceased to give out smoke gradually forward, and giving the new supply at a distant door, so as to cause the smoke to pass over a clear fire, by which means it will be completely burnt, the unavoidable leaking in of atmospheric air being sufficient to produce that result; an additional supply may, however, be given should it be found necessary. W, W, Fig. 872, is a waste-steam pipe leading from the ordinary safety-valve into the ash-pit D. This pipe will conduct the steam that escapes through the valve, whether in small or large quantities, into said ash-pit; and when the quantity is large from the effect of too great pressure, the steam will have the effect of damping the fire, and thus of regulating the pressure.

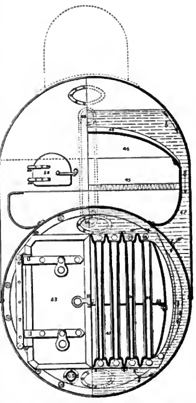
Montgomery also introduced a peculiar method of applying expanding-rods to boilers, for the purpose of preventing explosions by damping the fire before the point of danger was reached.

One form of this arrangement is shown in Fig. 873. *s*, *s*, is a rod which is made fast to the front furnace-plate, as at *t*. It passes through suitable stays to prevent its bending, is jointed at its rear end to a rod *u*, and this at its opposite end is jointed to a rod *v*, *v*, that passes to the front of the boiler; *w* is a rod that passes from the rod *w*, through a stuffing-box *x*, and is made fast to an immovable bulkhead at *y*; the rod *w* consequently remains stationary; the expansion of the boiler and rod by heat will therefore have the effect of causing the boiler to slide back on the rod *w*, and will cause the rod *w* to force the rod *v*, *v*, forward. The rod *v*, *v*, passes through a stuffing-box at a^1 on the front of the boiler, and its end bears against a rod b^1, which is attached by a joint-pin to a short arm or stud c^1.

In the vertical section, Fig. 872, the lever b^1 is seen as acting against a lever which operates on a valve e^1 that is connected to the steam-pipe R by a smaller pipe f^1. When the expansion-rods

force out the valve e^1, steam will pass up the tube g^1, and force in a piston at h^1, and will close the damper i^1 by an arrangement of levers, the action of which will be readily understood on inspection. To cause the lever d^1 to return with certainty to its place when the expansion-bars contract, a weight j^1 is applied to a cord that passes over a pulley k^1. The front of the furnace, it is to be observed, is to be so stayed that the whole expansion of it and of the boiler shall be towards the back. Montgomery says, "Instead of carrying the steam from the ordinary safety-valve through the waste-steam pipe W, W, as before mentioned, I sometimes adopt the arrangement of admitting a portion thereof by the action of the expansion-rods. In this case, in addition to the ascending-tube g^1, g^1, that gives a passage to the steam that is to close the damper i^1, I allow a tube g^{11} to descend from the chamber of the valve e^1 and to enter the ash-pit; the portion of steam that descends through this tube will co-operate with that which ascends through the tube g^1 in damping the fire. The expansion-bars are to be made of any suitable composition, and these, when the boiler is of iron, are to be enclosed in tubes of iron, the expansion of which will be the same with that of the boiler; when the boiler is of copper, the enclosing-tubes must be of that metal. By the enclosing-tubes the expansion-bars are kept from the contact of moisture, and all galvanic action is thereby prevented. The operation of the expansion-rods, when arranged in the manner described, will be such as to ensure the operating of the whole amount of their expansion upon the apparatus by which the damping of the fire is to be effected."

874.

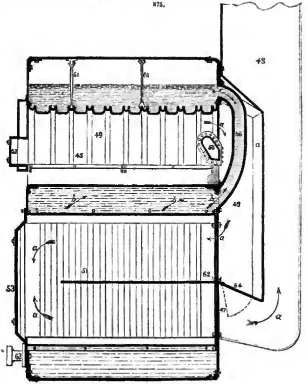


As an inventor, Montgomery has but few equals. We therefore give another form of boiler invented by him about 1859. This boiler is shown in Figs. 874, 875, 876, 877. In part a front elevation, Fig. 874, and in part a vertical transverse section, Fig. 874. The parts shown in these four figures are referred to by numbers instead of by letters.

Fig. 875 is a vertical longitudinal section; Fig. 876 is a transverse section of the upper part of the boiler, exhibiting a modification in the form of the crown-plate; Fig. 877 is a longitudinal interior view of a segment of the cylindrical portion of the boiler, showing the form of passages communicating between the upper and lower portions. 45 represents the furnace, and 46 and 47 flues through which the products of combustion pass to the stack 48; 49 is a corrugated plate of metal, forming the crown of the furnace and the floor of the upper water-space; 50 is a bridge, which serves to deflect the products of combustion upward, and receive the heat therefrom, which is imparted to the body of the water which it contains; 51 are corrugated metallic plates, forming a series of tubes of oblong, elliptical, circular, or other section, between which the products of combustion pass, and through which water circulates or flows upward by the effect of heat, to facilitate which the said tubes are formed of increasing diameter towards their upper ends. The plates are made of greater thickness at their lower parts to preserve them longer from the destructive effect of the deposit of ashes between them. 52 are the fire-doors, and 53, doors giving access to the flues: 54 is a damper which, when open, affords direct communication between the furnace and stack to facilitate kindling the fire. The plates by which the corrugated tubes are sustained and connected at their ends may be either cast or wrought metal. In the former case the ends of the tubes are first upset so as to form flanges, which may be separated and turned to different angles. The tubes are then placed in position in a suitable mould, and molten metal run upon their ends so as to cement the whole firmly together, or form means of connecting them as may be desired. In order to fix the tubes in wrought metal plates, apertures of the requisite size and shape are first formed in the said plates and the tubes inserted therein: the ends of the tubes are then somewhat expanded, and thimbles (56) inserted, which form internal supports, and enable the ends of the tubes to be upset or caulked so as to produce secure steam-tight joints between them and the connecting-plates (58). If preferred, the thimble may be replaced by a simple stay introduced between the opposite salient portions of the plates near their edges. The whole nest of corrugated plates forming the interior water-spaces is held in position by screw bolts (59), which admit of the removal of the whole nest bodily for inspection, cleansing, or

repairs, and the connecting-plate may, if desired, be constructed in sections connected in like manner so as to facilitate the same end. The corrugations in the metallic plates are advantageous in giving strength and rigidity to the structure, and affording an increased extent of heating-surface; and, when placed at right angles to the line of draught, present surfaces against which the products of combustion impinge with some force, and thus temporarily arrest their progress, and cause them to part with more of their contained heat. By means of this arrangement a large portion of the heat produced passes immediately into the upper part of the water through the

875.



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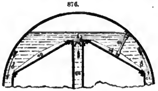

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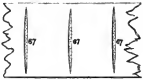

medium of the plate (49), and thus effects the generation of steam, the heat evolved by contact with the plates or tubes (51) serving to raise the temperature of the water contained between them, and to generate an additional amount of steam. When employed for the formation of furnace crowns and plates as (49), the corrugations are preferred to run transversely of the arch or at right angles to its axis, in order to form opposing curves to add to the strength and rigidity of the structure, which end is further accomplished by forming the corrugations of greater depth towards the centre or crown of the plate than at or near its sustained edges or ends, as shown in Figs. 874 and 876. The crown-plate (49) exhibited in Fig. 875 presents in its longitudinal section alternate corrugations of different sizes surmounted by vertical ribs or laminæ (60), which is believed to constitute an original form of plate, possessing greater strength in proportion to the weight of metal than any other known; the ribs (60) also afford facility for the attachment of stays or

braces (61). In high-pressure boilers the corrugations in the plates (51) forming the internal water-tubes will also be rolled of increasing depth toward the centre to give them additional strength. For low-pressure boilers the plates (51) are formed with corrugations running horizontally as well as vertically, the effect of which is to avoid any injury by contraction and expansion from changes of temperature, and also to afford increased heating-surface. In this case the tubes are made circular in the general form of their transverse section.

The operation is as follows:—The products of combustion pass from the furnace (45) over the bridge (50), down the flue (46) to THE DIAPHRAGM-PLATE (62), by which they are deflected horizontally between the corrugated tubes (51) to the end of the said plate (62), where they descend and are carried horizontally in the opposite direction between the lower ends of the tubes (51), and having thus been made to part with a large proportion of their heat, pass upward through the side flues (47) to the stack (48), their course throughout being indicated by arrows *a*. By this means the plates composing the water-tubes are preserved from unequal vertical expansion in their front and rear portions respectively, and the corrugated form of the said plates prevents any injurious results from the greater horizontal expansion of the upper than that of the lower portion. Feed-water (see arrows *b*) is introduced into the lower portion of the boiler through the port (63), and in accordance with the laws of rarefaction by heat a constant circulation is produced, the hottest portion of the water at all times passing to the upper region of the boiler immediately above the furnace, at which point the most intense heat is imparted from the furnace so as to produce there the chief generation of steam, which rises freely in the steam-space without producing any serious ebullition or disturbance of water to cause foaming. In the lower region of the boiler a constant circulation of water occurs up the tubes (51) and down the external water-ways (65), any steam generated by contact with the upper ends of the tubes rising, together with the water with which it is mingled, through the passage (66), and "solid" water descending through the external passages (67) to take its place: it will thus be seen that the present arrangement causes the steam as fast as formed to rise with the water instead of through it, which results in the prevention of foaming and in keeping the water in close contact with the heating-surfaces. The passages (67) communicate with the lower region of the boiler by long narrow ports (67^1) running transversely of the boiler, as shown in Fig. 877, which produce no weakening effect, because their combined diameter longitudinally of the boiler is not greater than that of the rivet-holes necessary for connecting the plates. In Fig. 875 the damper (54) is shown located at the bottom of the descending-flue (46), in order that when it is opened any accumulation of ashes may be discharged into the box beneath, from whence it is readily removable; the action of this damper also facilitates the kindling of the fire.

In a paper, by Charles Wye Williams, printed in the 'Trans. of Inst. N. A.,' on the "Construction of Marine Steam Boilers," Williams says that it is highly desirable to raise a preliminary question, namely, how to realize the greatest calorific effect from the coal by generating the largest amount of heat; and it is only when this is effected, that we come, practically, to the application and utilization of that heat in the boiler, and thus to generating the largest quantity of steam. In speaking of the power by which the engine is made available, we rightly refer to the steam itself. So, when we speak of the amount of power exercised, we refer, practically, to the quantity of steam generated. We may here, then, discard the term *pressure*, so much commented on, because this, when rightly understood, represents but the mere *quantity* confined within the volume of the boiler. On what, then, does this quantity depend? not, certainly, on the mere weight of coal consumed, since any weight may be so misapplied or wasted under an inefficient boiler as to have little effect on the quantity of steam generated. In the generation of heat, the only ingredients are the fuel and the air. Their successful combination belongs to the proportions and appendages of the furnace, wholly apart from the *boiler* placed over it, the result depending solely on the perfection with which that combination is effected. Now, that combination, says Williams, is a purely chemical process, and is determined by the union of due equivalents of the air and fuel. The perfection of this process, however, be it ever so complete, has no fixed relation to the amount of steam generated. To speak, then, in the fashion of the day, of the evaporative value of any description of *coal*, is at once incorrect, delusive, and unmeaning. Strictly speaking, there is no such thing as an *evaporative value* in coal, although we can well understand its heat-generating or calorific value. The generation of heat is a wholly different thing from its application. The importance of this distinction has yet to be appreciated by practical engineers. As the generation of heat is the peculiar province of the *furnace*, or alembic, in which the combustible fuel and the atmospheric oxygen are to be combined, so the generation of steam is the province of the *boiler*, and to this latter belongs the degree of perfection with which that heat will be transmitted to the water, and steam thus produced.

We have, then, two distinct processes or operations to consider: first, the generation of the heat; and secondly, its application, involving the heat-transferring property of the boiler-plates as the direct cause of the generation of steam. To the confusion which has hitherto prevailed in reference to these distinct processes may be attributed the absence of attention to the proportions, conditions, and separate functions of the furnace and the boiler. The consequence of this confusion is, that a wrong direction continues to be given to the inquiries of even the most ingenious and practical men. While we have been endeavouring to ascertain the relative calorific (erroneously called the evaporative) values of different kinds of coal, we should have been considering the relative heat-transmitting properties of the different kinds of boilers. Of this we have a notable instance in the late commission issued under the direction of the Admiralty, to inquire into the kind of coal best suited for steam-vessels of war, but in which no reference whatever was made to the peculiarities and imperfections of the boiler employed, and hence the unsatisfactory character of the results, as will hereafter be shown. On this head we have also a report from the late H. De la Beche and Lyon Playfair on the so-called "evaporative power and value of the North of England and South Wales coal." This report assigns to the latter an

evaporative value, which is purely theoretical, and altogether erroneous and misleading. In it we detect the grave error of confounding calorific with *evaporative* power, which are there assumed to be identical.

In considering the calorific value of any description of coal, we cannot omit estimating that waste of its constituents which goes to the production of smoke, and the deposit of soot, with its non-conducting property, but which forms no part in a theoretic estimate of its calorific properties. On this point R. Murray has offered some remarks which here demand attention. "However desirable it may be," observes Murray, "in other respects, to 'burn smoke,' by admitting air into the furnace above the bars, this is not always found to be an *economical* process." It is to be regretted that he has offered no evidence in justification of this statement, which, says Williams, I hold to be the very reverse of fact. I can at any time show a boiler in daily work, in which, not only the full calorific value of each description of coal may be ascertained, but in which the economy of combustion with, and without, smoke, is indicated with the greatest certainty. Again, Murray in his paper observes, "the burning of smoke, as it is called, by artificial methods, has not proved very successful in economizing fuel; but that, by proper firing, and by admitting a little air through the doors, black smoke may be prevented from being formed, and more economy would in that way be realized than by using artificial means for burning the smoke." In making these assertions, Murray should have supplied some information as to what he means by the term "artificial;" what it is that he characterizes as "proper firing;" and what is meant by "a little air." Murray, observed Williams, must have been looking at some of the scores of patents, ingeniously varied and elaborated as mere commercial speculations, for effecting, by costly apparatus, the "burning of smoke;" and which may truly be called "artificial," including the most absurd of all, the heating of the air. But if he will refer to the Newcastle experiments he will find, not only that smoke may be prevented, but that a considerable economy may at the same time be uniformly realized. As to the term artificial, if that be applied to the method of introducing atmospheric air, in divided streams, into the furnace, a system which—in continuation Williams goes on to say—I have employed for many years with very great advantage, I can only say that Murray may with equal propriety characterize as artificial the method of allowing water to issue through the perforations in the rose of the common watering-pot, instead of its passing in an undivided stream, as when the rose is removed. This action of the rose is identical with the mode recommended for bringing the air, in divided portions, to the gas in the furnace, for the purpose of a more rapid intermixture. As to admitting a little air, it would appear that the author alludes to the common practice among stokers of opening the doors to a small extent. It ought to be remembered, however—what every chemical authority states—that the 10,000 cub. ft. of gas generated from a ton of Newcastle coal, absolutely require for their combustion no less than 100,000 cub. ft. of atmospheric air, and practically, as Daniel observed, require fully double that quantity for the ordinary working of a furnace; and this independently of the 200,000 cub. ft. required for the coke or fixed portion of the same ton weight, and which must pass up from the ash-pit. The following proof of inattention to these large quantities may here be mentioned. In a large steamer with great power, a difficulty was experienced in raising the required quantity of steam, and the continued discharge of the densest smoke (where the engineer had undertaken that there should be *none*) caused great annoyance. The remedy adopted was the passing of *one of the 2½-in. tubes* through the smoke-box into the stoke-room, and thus allowing the air to pass through it to the gases before entering the tubes! It need only be observed that it had no more effect than if the nozzle of a common hand-bellows had been applied. To speak, then, of allowing a little air to enter by the doors, seems likely to mislead, where such large quantities of air are chemically essential to the process. Williams further asks, Where else, then, above the fuel, that is, in the chamber of the furnace (as in the retorts in the gas-works), can the combustible gas be met with, or where else can this enormous quantity of air be required to effect the necessary union and combustion, without which the full calorific and economic value of the coal cannot be realized?

In great operations like these, there can be no advantage in neglecting or counteracting the demands of nature, or in checking the operation of nature's laws. All admit that gas is generated from coal, on its being heated; that atmospheric air is essential for the combustion of that gas, and that the two must be intermixed for chemical combustion; yet we violently interfere by allowing neither time nor space for these operations, and in most cases absolutely prohibit the introduction of any air at all, by the interposition of closely-fitting doors! What, then, can we expect but imperfection in the process and the most unsatisfactory results! Is it not, in truth, worse than stupidity or folly to neglect the conditions and means by which alone the constituents of the fuel can be enabled to unite, and combustion be effected, or the full calorific value of the coal be realized?

On one occasion which came within my own notice, and where the door-plate box had been fitted with the proper number of orifices, the engineer observed that my own plan had been adopted. In reply, I asked if he had ascertained that any, even the smallest quantity of air had passed in through the 300 ½-in. orifices. The orifices were duly provided, and it was assumed, as a matter of course, that the air would enter through them. On investigation, however, it was found that no air whatever had passed inwards through those holes. The furnace-bars being 7 ft. long, and the chamber so shallow that the fuel actually touched the crown of the furnace, the back ends of the bars were necessarily uncovered, and the volume of air which there entered was so great that the space over the bridge was insufficient for its passage, and consequently, instead of any air passing inwards through the perforated door-plate, much of the air and products of combustion (the flame included) actually went the wrong way, returning, and forcing the flame against the door-plate, and outwards through the holes, so as to destroy the door, producing what is known by the term "back-draught."

Williams, in continuing this argument, remarks that Murray has stated that not only is economy not effected by admitting air into the furnace above the bars, but "considerable caution

is necessary for the due regulation of the quantity of air thus admitted through the fire-doors." To these statements, says Williams, I can in no way assent. The following proofs may at any time be tested by Murray in my own furnace and boiler, which are freely used by the coal-owners of Lancashire and other counties for testing the calorific values of their several coals, as before shown. Throughout the following experiments the same coal was used. In No. 1, the air was freely admitted through 342 ⅜-in. holes in the door-box, as was done at Newcastle, no caution whatever being necessary. In No. 2, these orifices were closed, and the door was the ordinary one as generally used.

	Coal used.	Water evaporated.	Water evaporated per lb. of Coal.	Pyrometer Heat in Chimney of escaping Product.	Remarks.
	lbs.	lbs.	lbs.	°	
No. 1 ..	268	2534	9·45	1212	No smoke.
No. 2 ..	395	1781	4·50	847	Much smoke.

With reference to the absence of economy on the one hand, and the "considerable caution" required on the other, I here quote, in further opposition to both assertions, the words of the three professional umpires at Newcastle—Armstrong, Richardson, and Longridge—on the point of admitting the air at the door-end of the furnaces. In their published reports they say, as to steam generated, "there was a large increase above the standard in every respect." Again, "The prevention of smoke was, we may say, practically perfect." Again, "No particular attention was required from the stoker; in this respect, the system leaves nothing to desire."

"The results show a large increase above the standard in every respect. The prevention of smoke was, we may say, practically perfect, whether the fuel burned was 15 lbs. or 27 lbs. per sq. ft. per hour. Indeed, in one experiment we burned the extraordinary quantity of 37½ lbs. of coal per sq. ft. per hour upon a grate of 15½ sq. ft., giving a rate of evaporation of 5½ cub. ft. of water per hour per sq. ft. of fire-grate, without producing smoke. No particular attention was required from the stoker; in fact, in this respect the system leaves nothing to desire, and the actual labour is even less than that of the ordinary mode of firing."—*Report on Williams's System.*

"Mr. Williams's system is applicable to all descriptions of marine boilers, and its extreme simplicity is a great point in its favour."—*Report of Armstrong, Richardson, and Longridge.*

In further corroboration of these returns, we have also the authority of the two professional gentlemen, Miller and Taplin, deputed by the Admiralty to report on "the evaporative power and economic value of the Hartley coal and Welsh steam-coal." In their report they state that they inspected a modification of my plan for the admission of air into the furnace, and found the prevention of smoke to be almost perfect. Also, that on the 3rd of August they inspected the apparatus in the 'Expert,' steam-tug, and, "as they were on board for several hours, they had every opportunity of seeing the effect of making and preventing smoke; and although there was no very careful stoking, yet the prevention of smoke was *almost perfect.*"

Having explained the necessity of considering the calorific or heat-generating property of the coal, apart from the steam-generative property of the boiler, Williams next examines the latter in reference to its heat-absorbing faculty.

In coming to consider more closely the heating-surface of the tubular system, Wye Williams observed, I would first insist upon the importance of increasing the efficiency, rather than the mere gross *area*, of such surface. This should be the first consideration. The area of surface in the boilers of the present day is already greater than would be necessary were it more efficient as a heat-transmitter. Numerous instances indeed might here be given of a very large reduction of the surface having been made by the removal of many tubes without any appreciable result. I have even known boilers to be improved by having several tubes removed and the tube-plate patched over the places from which they were taken out. The accompanying drawing, Fig. 878, of the face-plate of the Holyhead steamer, the 'Anglia,' illustrates a case of this kind. The question of efficiency, as contrasted with mere area of heating-surface, is by far the most important, although, strange to say, it is the most neglected. In this direction alone may we expect the greatest measure of improvement of which boilers are susceptible. The evil of an insufficiency of steam, notwithstanding an ample area of so-called heating-surface, at once raises the question as to the demerits of the tubular system. The prevailing type of modern boilers, whether for railroads or for steam navigation, is characterized as the multitubular boiler. In the multitubular system the heated products pass from the furnace through a series of metallic tubes, varying from 6 to 10 ft. in length, and from 1½ to 3 in. in diameter. The avowed object of this subdivision is to increase the aggregate of surface to which the heat is applied. This system of subdivision of the heated matter is, however, prejudicial both in a

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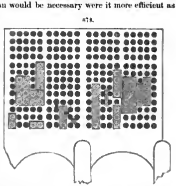

chemical and mechanical point of view, by attenuating its effect. This type of boiler being now so general, an inquiry into its origin is not only necessary in explanation of its adoption, but as a means of tracing and correcting the error into which we have fallen.

The tubular system was first adopted by George Stephenson in the locomotive, the 'Rocket,' by which, in 1830, he won the prize of 500*l.* on the Manchester and Liverpool Railway. The use of tubes in the 'Rocket,' at the suggestion of Henry Booth, the treasurer and most influential member of the company, was then accompanied, *and for the first time, be it observed*, with the passing of the waste steam from the cylinders through the chimney. The result of this combination of tubes and artificial draught was so successful and so unexpected as at once to be considered conclusive, and to leave no room for doubt or inquiry. The steam-jet in the chimney created, in fact, so powerful a draught as to secure an adequate combustion of the fuel, with the generation of a corresponding sufficiency of heat, while the tubes, by reason of the large surface they presented, were assumed to supply the other desideratum—the application of that heat in the generation of steam. Had, however, the two principles been separately applied and examined, and estimated according to their relative and respective merits—which never was done—it would have been found that nearly the whole of the favourable result obtained was really owing to the steam chimney-jet, and the powerful draught it occasioned. The value of the combined action of the jet and of the tubes, however, was taken for granted, and has since been considered the perfection of efficiency.

The value of the steam-jet, and of the increased draught it occasions in locomotives, has been too well established to require any remarks; I will (continues Williams) therefore confine myself to the use of the *tubes*. It is manifest that the main difficulty under which engineers labour, as regards marine boilers, consists in providing adequate heat-transmitting surface. This difficulty early suggested itself to the elder Stephenson. Smiles, in his biography, tells us that his son, the late lamented Robert Stephenson, observed, "Other engines with a variety of constructions were made, all having in view the increase of the heating-surface, as it became obvious to my father that the speed of the engine could not be increased without increasing the evaporative power of the boiler." This inference was strictly correct; his error (hitherto unexamined and uncorrected) lay in the hasty and inconsiderately-formed assumption that an increase in the evaporative or steam-generative power would necessarily be secured by an increase in the tubular surface. This error, therefore, naturally led him to an extension, not only of the number of the tubes, but to give them the length of even 13 ft. So fully was Robert Stephenson impressed with the idea, that he observed, "The power of generating steam was prodigiously increased by the addition of the multitubular system." That this inference was erroneous, is clear from the fact that the 'Rocket' had but twenty-five tubes of 3 in. in diameter and 6 ft. long, and the entire tubular surface had but the insignificant aggregate of 117$\frac{3}{4}$ sq. ft.—an amount of surface which would excite the smile of modern engineers at the idea of its "prodigiously increasing" the generation of steam. The insufficiency of so small an amount of surface to produce any noticeable effect was subsequently demonstrated by the fact that in the Newcastle boiler (to which was applied the apparatus to which the prize of 500*l.* was awarded) an addition of forty tubes with a surface of 320 sq. ft., and placed under the most favourable circumstances for transmitting heat, had but little effect, and could only extract 45° out of 600°—the temperature of the heated products passing through the tubes. "The heater, which was used for the purpose of heating the feed-water, slightly increased the evaporative effect by its additional absorbing surface. This increase was, however, much less than might have been expected from the large absorbing surface of the heater, which contained 320 sq. ft.; yet it was found that, when the products of combustion before entering the heater were at 600°, the passage through it did not reduce the temperature more than 40° to 50°."—*Report of Armstrong, Richardson, and Longridge.* It seems strange that this fact, so suggestive, and so prominently noticed and recorded, did not lead to further inquiry as to the cause of the manifest insufficiency of the heat-transmitting power of the tubular surface; nevertheless, this *combination* of the tube-surface system with the jet remains still unquestioned. "The superiority of the arrangement adopted in the 'Rocket,'" observes Smiles, "consisted in the rapidity of combustion in the fire-box keeping pace with the rapidity of motion in the locomotive itself; for, according as the strokes of the piston in the cylinder were fast or slow, so were also the jets of steam thrown into the chimney on which depended the draught of heated air through the tubes of the boiler, and consequently" (a manifest non-sequitur) "*the amount of steam generated from the water exposed to the large extent of heating-surface* which they presented." Here we see no indication of doubt as to the action of the tubular surface, which is set down as the unquestioned source of the generated steam. The trial with the 'Rocket' took place in 1830, and the supposed steam-generating value of tube-surface remains unquestioned to this day.

"It was not until some years after, when the tubular system was introduced into marine boilers, that I," adds Wye Williams, "began to entertain any doubts as to its merits. Aware of some experiments having been made on the Manchester and Liverpool Railway, I applied early in 1858 to Dewrance, then chief engineer to that railway, and here give his reply to my inquiry. He said:—'In reply to your inquiries as to the experiments made by myself and Woods, about the year 1842, as to the evaporative effect of the *tube* portion of a locomotive boiler, I have to say that we had one of the boilers employed on the Liverpool and Manchester line divided, so as to separate the water in the *tubular* portion of the boiler from that in connection with the fire-box portion. In a subsequent experiment, I divided a small boiler into six different compartments, so that I could ascertain the weight of water evaporated in each. The first compartment was but 6 in. long, the remaining five were each 12 in.—the tubes being 6 ft. 6 in. long. The result was, that each square foot of the heat-absorbing surface in the first compartment was about equal to a square foot of the fire-box surface. In the second compartment each square foot of tubular surface was estimated at about one-third of that value; but in the remaining four compartments the evaporation was so small as to raise a doubt on my mind whether it had any value at all. In fact, I came to the conclusion that the first 6 in. of the tubular series had more evaporative effect than

the remaining 60 in.' Here was ample encouragement for further inquiry, the heat-transmitting property of the tubular surface being so seriously impugned. A similar experiment had been made by the late Benjamin Hick, of Bolton, a competent and able experimenter. The conclusion that he came to was, that each 10 ft. of tube-surface had only the heat-transmitting power of 1 ft. of furnace-surface. My own experience goes far in corroboration of these data, as will presently be seen."

To exemplify these facts, Williams had a boiler so constructed that the heat-transmitting value of each lineal foot of tube should be indicated with absolute certainty. The tube was 3½ in. diameter, similar to those in the 'Eblana' steamer. It was 5 ft. long, and divided into six compartments or separate boilers, as shown in the annexed engraving.

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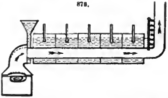

Observing that the boiling, which was violent, always appeared to come exclusively from the end next the plate in which the tubes were inserted, the first compartment was confined to a single inch of the tube, the second to 10 in., and the remaining four compartments, each to 12 in. The following is the result after three hours:—

First Compartment, of 1 inch, evaporated.	Second, of 10 inches.	Third, of 12 inches.	Fourth, of 12 inches.	Fifth, of 12 inches.	Sixth, of 12 inches.
lbs. oz.	lbs. oz.	lb. oz.	lb. oz.	lb. oz.	lb. oz.
2 14	2 15	1 14	1 6	1 2	1 1

Here we see the first single inch of the tube evaporated nearly as much as the adjoining 10 in., while the first 11 in. did more than the remaining 48 in.

Desiring to place this beyond all question, and thinking that objection might be made to the results obtained from a single-tube boiler, Williams subsequently had a boiler constructed with twenty-five tubes—the exact number of the 'Rocket' boiler—6 ft. long, and 2¼ in. internal diameter. This boiler he divided into three compartments, by water-tight partitions placed 1 ft. from either end, thus leaving a central compartment 4 ft. long. Having connected this boiler with a suitable furnace, he found that the water in the first compartment, which received all the heat transmitted through the tube-plate, boiled in twenty-three minutes from the time of lighting the fires; that in the second compartment it took forty-eight minutes to boil; and that in the last compartment it did not boil until fifty-nine minutes had elapsed. During three hours of uniform firing, the following results were obtained. In the first compartment, a foot long, 240 lbs. of water were evaporated; in the second compartment an average of only 70 lbs. of water for each foot of length was evaporated; and in the last compartment, a foot long, only 50 lbs. of water were evaporated.

Having thus established the fact of the great evaporative efficiency of the first compartment of the tube, and especially of the first inch, in length, PRACTICALLY THAT OF THE FACE-PLATE, and the comparative inefficiency of the remaining 5 ft., it became necessary to examine the cause of this extraordinary result, to find out how it happened that a stream of heated products at a temperature above 600° passing continuously for three hours through the tube, was incapable of transmitting more heat to the last 12 in. of its length than could keep the temperature of the water at 180°. In the fact that it was so, we at once see the inutility of increasing the length of the tube. Let us first examine the area of heating-surface in a few vessels of the largest class. The published authoritative account of the American iron-clad floating battery, by Mr. Stevens, gives the following details:—

	sq. ft.
Tube-surface	23,380
Furnaces	2,050
Connexions	1,890
Tube-sheets	680
Total	28,000

Here the gross area of tube-surface is estimated in the same category with that of the furnace-surface. Now, in taking the true value of tube-surface as stated by Dewrance, or Hick, these nominal 23,800 sq. ft. would be at once reduced to 2380: and this most probably is not far from the truth. Again, take the tube-surface of the late Brunel's boilers in the 'Great Eastern' (which are constructed on the same principle as the original boilers of H.M.S. 'Terrible') for each set of twenty-four furnaces (there being 112 in all) at 6000, and of furnace-plate at 3000 sq. ft.—say 28,000 ft. of tube-surface in all—and then see what a serious, though unsuspected reduction should be made in reducing those 28,000 ft. nominal, to effective heat-transmitting surface. Under such circumstances we cannot doubt the imperious necessity of the furnace-forcing system. Again, let us examine the tube and furnace surface of one of the Holyhead steam-packets of 750 nominal horse-power:—

Tube-surface in eight boilers, with 40 furnaces, in square feet	15,600
Furnace ditto	1,960
Back, side, and top of uptake	1,108
Tube-plates between the tubes	316
Total	18,984

We here see again how much larger in proportion is this nominal *tube*-surface than that of the *furnace*, and how much more serious is any default in its efficiency, there being in this case $20\frac{3}{4}$ superficial feet of tube-surface per nominal horse-power. In these boilers the tubes are 6 ft. 2 in. long, and but $2\frac{1}{4}$ in. diameter.

Again, we have the iron-clad steam-vessel, the 'Warrior,' the type of whose boilers, according to the published accounts, is identical with that of the Holyhead steam-packets, but with both tubes and grate-bars 6 in. longer. In this vessel there are no less than 4400 brass tubes of 6 ft. 6 in. long by $2\frac{3}{4}$ in. inside diameter. In the new war-vessel, the 'Octavia,' we have the same identical type of boiler, and excess of tube-surface.

In opposition to all this, Williams stated that in one of the most efficient boilers, as regards the sufficiency of steam, in the fleet of the City of Dublin Company, the tubes are but 3 ft. long, and the relative proportion of tube-surface to flue-surface is but as $2\frac{4}{10}$ to $6\frac{1}{10}$ the nominal horse-power. The contrast is most remarkable. The merit of that boiler doubtless arises from the circumstance, that the shortness of the tubes leaves a large chamber for the combustion of the gases to complete itself in before the products approach the tubes.

Now, how are we to account for the fact that the several designers of the boilers before spoken of have adopted almost identically the same description of boiler, with the same objectionable features? At first sight, it would appear that all had been convinced of its practical superiority. This would be a reasonable inference had it been the result of well-established experience. No experiments, however, having been made for testing the heat-transmitting power of tube-surface, apart from other considerations, we have no alternative but that of attributing this singular coincidence to the desire of avoiding that responsibility which would attach to any great deviation from existing practice. Here, however, we have, in all, the same objectionable length of furnace-grates—the same absence of all means of admitting air to the generated gases—the same want of space between the fuel and the tube-face plates—and the same absence of a combustion-chamber, although all improved locomotive engineers are studious in providing such means of promoting the use of coal on the railroads.

The great error into which we have fallen, in the absence of experiment, is an over-estimation of the heat-transmitting property of the tube-surface. In our calculation of the steam-generative power of the boiler, we assume it to be always proportional to the number of square feet of the surface exposed. Now, this calculation is made without reference either to the rapidity with which the current of heated products passes through the tubes—to the diminishing rate at which the tubes transmit heat in proportion to their length—or, worst of all, to the direction in which these products strike or impinge upon the tube-surface. If it were true that each square foot of metallic surface really possessed a given or known amount of heat absorbing and transmitting power, whatever that might be, an increased number of square feet would necessarily represent a commensurate increase of the steam-generative power. The real value of the so-called heating-surface, however, depends on so many contingencies, that calculations based on the mere gross area of surface exposed must be utterly valueless. We have here, then, the important question raised,—What value are we to attribute to such surfaces? The single fact of the very high temperature of the escaping products in the chimneys of marine boilers, is alone conclusive of the deficient heat-transmitting faculty of the surface of the tubes. Our purpose, then, should be, not to increase the number or length of the tubes, or the sum of their surface-areas; but to render these surfaces more effective as heat-transmitters. In manifest neglect of this purpose, we find in the boilers of the most recent construction, and even in war-vessels, the greatest possible number of tubes, and of the greatest length, crowded together without regard even to the water-spaces between them, which are often restricted to but half-an-inch. The result is, that in the absence of sufficient water-spaces, particularly at the end where the heat first strikes the face-plate, the tube-ends are exposed to the greatest heat, and they soon begin to weep; the face-plate itself begins to crack, and the space where the water should have the freest circulation becomes choked up with the solid matter of incrustation. Samples of this matter here exhibited afford sufficient proof of the fact.

Wye Williams remarks that, in a recent publication, we are told that "marine boilers require 5 sq. ft. of heating-surface, and one-fifth of a square foot of fire-grate surface for every indicated horse-power." Here is a calculation supposed to be based upon some reliable data; we shall see, however, that all such calculations are but as the "baseless fabric of a vision." It may be asked, indeed, if the writer had ever inquired what the value of a square foot of heating-surface, or of fire-grate surface, really was? Yet, from the affected precision of the author in other respects, we might be led to suppose that both had been reduced to some standard, or in fact were constants. Nothing, however, can practically be more vague and misleading. The value of a square foot of fire-*grate* surface, for instance, will depend: first, on the nature of the coal as bituminous or otherwise; second, on the quantity of gas it produces; and third, on the amount of draught passing through the furnace from the ash-pit. On the other hand, the value of a square foot of *heating*-surface will depend mainly on the direction in which the current of heated products obtains contact with the metallic surface. This last, though the main element of success, yet, strange to say, is the very one which is not only overlooked, but absolutely ignored in all modern practice.

Of the practical errors committed in the mode of estimating the steam-generative value of the tube-surfaces, we have an instance in a recent publication professing to give the results of the most improved systems, where it is stated, as a leading principle, that direct impact with the heat-absorbing surfaces should be *avoided*. That this is a prevailing error is confirmed by Robert Murray, who, in one of his publications, has laid it down as a principle, that "*elbows are to be avoided*;" in other words, that the current of heated matter passing through flues or tubes should not be broken, bent, or interrupted, or the straight line of their course disturbed. Now, said Williams, in the paper from which this extract is taken, I am prepared to prove, on the contrary,

that the direct reverse of this instruction is essential to success; and upon this I insist. If the author had said, that the direct impact of *flame* should be avoided, with the view of preventing the formation of smoke and soot, he would have stated a correct chemical fact. Direct impact of the heated products, *after* the combustion of the carbon of the flame, is, however, precisely what should be promoted. Practically, it will be shown that the absence of direct impact is the main source of inefficiency of modern tubular boilers, and the cause of that great escape of heat by which the uptake and chimneys of marine boilers are so over-heated and destroyed. And in this respect, I hesitate not to say that the multitubular system is largely and radically deficient in the heat-transmitting faculty. The main point, then, for consideration is, how to make any given surface more effective as a heat-transmitter, and what are the conditions on which the transmission of heat depends. This, *cæteris paribus*, as regards the rate of current of the heated products, will depend on the direction in which those products are brought into contact with the plate or tube-surface—whether by a *direct*, *diagonal*, or *parallel* action. On this point it may be stated, as the result of actual observation and experiment, that a square foot of surface on which the heated current strikes with a direct impact (that is, at right angles to the surface) will be equal to 4 ft. where the direction is diagonal, and to double that where the current runs parallel, or in the same plane as the metallic surface. In estimating the action of a heated current passing through tubes, we ordinarily overlook the fact that gaseous matter (that is, the products after combustion), whatever may be its temperature, radiates but little, if any, heat. Radiation can alone proceed from solid matter. It is this which enables visible flame to radiate so powerfully; visible flame being merely an aggregate of myriads of solid carbon atoms, still unconsumed, and at a white heat, or, as estimated by Davy, at 3000°. Now, the products of flame, after combustion, and when passing through the tubes, are transparent, and transmit little or no heat by radiation. It is by their contact alone with the metallic surface that heat is communicated and transmitted.

Again: that but little heat is transmitted when smoke is formed in a flue or tube, Williams goes on to say, I have repeatedly proved, by the introduction, through the smoke-box, and into the tubes, of an iron rod, to the end of which were attached pieces of paper and shavings. After remaining some time, they have been withdrawn, yet, although their *outsides* have been covered with black soot, their *insides* have not even been discoloured by heat. When, therefore, we see a volume of smoke issuing from the chimney, we may be assured that the tubes are full of it, and that the temperature within them is not much greater than the hand could bear.

Let us now suppose a column of heated products entering and passing through a tube, as a cylindrical shot does through a cannon. Contact is then alone obtained between the outside section of such column and the metallic surface. This section having given out as much heat as possible in the fraction of a second (the time which its transit occupies), the interior portion of such column passes onwards undisturbed, carrying its initial temperature to the exit. In no other way can we account for a column of products above 600° of temperature, passing continuously, and for hours, through and along the interior surface of a tube, and yet giving out no more heat than can keep the water at 180°.

Let Fig. 880 represent a longitudinal section, Fig. 881 a cross-section at the entrance, and Fig. 882 a similar section at the exit of a tube. The several lines are here supposed to represent the sections or strata of the heated products passing through it, entering at a temperature of 700°,

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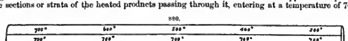

882.

and issuing at 540°. In this case, the outer section, being next, and in contact with, the iron-tube surface, will give out heat, and be reduced, say to 300°, on arriving at the end of the tube. But what is to cause any interchange of position between it and the other strata?

To sum up the objectionable features of the tubular system—as exhibited, for example, in the accompanying diagram, Fig. 883, which represents a boiler of the modern type, as fitted in a large packet belonging to the City of Dublin Steam Packet Company—they consist: 1st. In an extreme length of fire-bar surface, often amounting to above 7 ft., a length which absolutely precludes the possibility of a stoker keeping the back-end sufficiently covered by fuel. 2nd. In long shallow furnace-chambers, in which the solid fuel on the bars necessarily occupies the entire space, reaching to the very crown-plates, as shown in the diagram—an arrangement by which neither time nor space is allowed for that gradual mixing and diffusion of the air with the gas generated from the mass of fuel, which are the *sine quâ non* of perfect combustion: in this respect we have the ordinary practice directly opposed to the sound conditions stated by Mr. Murray, when he describes the value and necessity of "large and high furnaces." 3rd. In the absence of due provision for the admission of the air either in suitable quantity, proportioned to the large evolution of gas, or in a manner adapted to its admixture and diffusion with the gas. 4th. In long and shallow ash-pits, by which the air, instead of gradually ascending through the bars from front to rear, is forced into a rapid current towards the farther end, where it is forced upwards with increased velocity, through the fuel on the farther ends of the bars, with the force of an artificial blast, causing a rapid combustion in that quarter, and thus leaving the bars uncovered, and the air free to pass upwards in a mass. 5th. In the absence of provision for the admission of a supplementary quantity of air behind the bridge. It is evident that where the furnace is long and shallow, as in Fig. 883, the fuel considerable, and the gas evolved necessarily great in quantity, any air that could possibly be

introduced at the door end must be wholly insufficient for the combustion of that gas. In such cases, the required quantity of air must be supplemented from the ash-pit and behind the bridge. The engraving, Fig. 884, shews the mode in which this was effected, and the air introduced through a series of $\frac{1}{4}$-in. holes in one of the City of Dublin steam-packets, and with decided success. The

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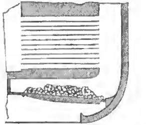

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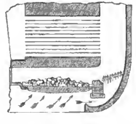


cost of the apparatus was too insignificant to merit attention. 6th. In the want of sufficient space between the bridge and tubes, as a chamber in which the necessary admixture of the air and the gas may be effected for combustion. Experience proves that, whatever may be the construction of the furnace or the boiler, a distance of from 6 to 8 ft. is absolutely necessary for that purpose. In this respect, boilers on the plan of the 'Great Eastern's' are peculiarly objectionable, no space whatever being allowed for the combustion of the large volume of gas generated from each of two long furnaces, which meet at the middle, and practically form one furnace of 18 ft. in length. The result is that much of the gas passes unignited and unconsumed through the tubes, to be ignited at the wrong end, and in the smoke-box, where it meets with a supply of air coming from those other furnaces in which the fuel at the time happens to be in a clear state, and their bars to a great extent uncovered. 7th. In an unnecessary and injurious length of tube, which is but slightly instrumental in producing steam, as will hereafter be shown, while it occupies a large space, much of which might have been appropriated as a chamber for the combustion of the gas, as is done in the most approved locomotives. 8th. In the absence of sufficient space for the presence and circulation of the water between the tubes, and especially at the end nearest the face-plate, against which the flame strikes with peculiar energy. In this respect, the marine tubular boiler labours under a serious disadvantage from which the locomotive is exempt. In the latter, the space occupied by the tubes and the furnace compartment is separate, the steam generated from each having its own proper place for its ascent. In the marine boiler, however, the tube series being placed directly over the furnaces, the great mass of steam generated directly from the latter has to work its way in its ascent through spaces which are not above $\frac{1}{2}$ or $\frac{3}{4}$ of an inch between the tubes. The result is that the tubes are surrounded by the mass of steam rising from the furnaces, and which practically drives the water before it, leaving the tubes without any. In this respect, the system is again directly the reverse of that very properly insisted on by Robert Murray, when he says, "that the steam should have a ready escape from every part of the heated surface." In the marine boiler we see that, instead of a ready escape, it has the greatest mechanical obstructions to contend with.

I must be allowed here to remark that the evils which I have pointed out are not peculiar to the boilers of any particular vessel, or set of vessels, but are to be found, on the contrary, in many of the finest and best ships in existence, including the 'Warrior' and 'Octavia' men-of-war, the fast Holyhead packets, and many other first-class vessels. It is not, then, to be wondered at that the coals most in favour are not those which would give the greatest calorific effect, if duly consumed, but such as would avoid the issue of dense smoke, and thus give the appearance of economy. It will be presently shown that the absence of smoke, in some descriptions of Welsh coal, is no proof of greater heating powers, or of a more economic fuel.

Looking, then, at the comparative inefficiency of the tubes, as steam generators, with the exception of the first 12 or 18 in. (which includes the action of the *face-plates*), and looking also to their peculiar position, we see them in the very place which, mechanically and chemically, is most appropriate for the combining action of the gas and the air—in a word, for a combustion-chamber. There appears, then, no alternative but that of dispensing with the use altogether of long straight tubes or flues. In truth, we cannot separate the existence of straight tubes from the vice of having the current of heated products passing in the same plane and direction as the surface through which the heat is to be transmitted. In this abandonment of the straight-tube system, it must be confessed that there are commercial difficulties which, it may be feared, will materially retard this useful change. On discussing the subject with a well-known engineer, and showing him, practically, the inutility of the tube-surface, particularly where long tubes are used, Williams continued to say, I was struck with the difficulty of obtaining his assent, while all other witnesses expressed their entire conviction in what they saw produced in the experimental boiler. On his departure, however, the mystery was solved, and my surprise at an end, when I was informed that he was largely connected in Birmingham, and even with a patent for an improved mode of welding them. It was thus manifest that personal interest was directly opposed to change, conviction, or improvement. I may here add that I understand several engine and boiler makers are in the same position, and have largely invested capital in the manufacture

of tubes. This, while it accounts for the difficulty in the way of improving our boiler system, increases the fear of its requiring a lengthened period before the necessary change and improvement shall be realized.

Under these circumstances, I may perhaps be permitted to suggest that the Admiralty, who can have no personal interest in the manufacture of tubes, have it in their power to do the public a most essential service by instituting inquiries into those practical defects of the tubular system to which I have drawn attention, and by lending their high influence to remedial changes. It would be a great stimulation to the progress of marine engineering if they would do this, and would, at the same time, institute more complete and satisfactory tests of their steam-ships. Either in place of, or in addition to, the ordeal of the measured mile, let them institute lengthened runs at sea, as is done with Clyde-built vessels, where the trial-trips generally involve a run from Greenock to Liverpool. In these trials let the Admiralty require official returns involving the following particulars:—1st. The speed *an hour*; 2nd. The actual weight of coals used *an hour*; 3d. The degree to which smoke is produced or avoided; 4th. The temperature of the stoke-hole; 5th. The temperature of the escaping products in the uptake, ascertained by the pyrometer; 6th. The weight of clinker and its peculiarities; and 7th. The weight of incombustible ash. The inspecting officer should also be required to report upon the extent to which forcing of the fires may have been resorted to.

It will be observed that these returns involve the qualities of the fuel employed, and of its fitness for use in the furnaces of the particular ship tested, as all such returns undoubtedly ought to include these particulars. In order to show that there is no great difficulty in obtaining such particulars, I may mention that they are all attended to in the tests of coal, made by their respective owners, in the test-boiler of the City of Dublin Steam-Packet Company at Liverpool, and are all so easily and accurately determined that the tests in question at once stamp the true character of each description of coal. In illustration of these results, I here give a return of ten kinds of coal, with their several calorific values taken from the results of some of the tests just mentioned.

TESTS OF COALS AS MADE IN THE BOILER OF THE CITY OF DUBLIN STEAM-PACKET COMPANY.

Denomination of Coals.	Total Water evaporated.	Total Coals consumed.	Total Time employed.		Coal consumed per hour.	Water evaporated per hour.	Water evaporated per lb. of Coal.	Pyrometer heat in Flue.	Temperature of waste Heat in Chimney.	Clinker per cwt. of Coal.	Ash per cwt. of Coal.	
No.	lbs.	lbs.	H.	M.	lbs.	lbs	lbs.	°	°	lbs.	lbs.	
1 Welsh.	8000	980	3	47	259	2114	8·16	1083	484	3·08	1·14	No smoke from any of the Coals, the combustion being made perfect in each case by the proper admission of air.
2 Welsh.	8000	898	4	30	199	1777	8·92	831	450	4·37	1·88	
3 Welsh.	8000	952	4	57	192	1616	8·40	739	450	5·17	1·88	
4 Welsh.	8000	784	4	41	167	1707	10·20	957	466	2·14	2·00	
5 Lancashire.	8000	1008	3	34	278	2242	7·98	1126	517	1·73	0·69	
6 Lancashire.	8000	896	3	42	242	2162	8·92	1079	535	2·78	0·34	
7 Lancashire.	8000	896	3	35	250	2232	8·92	1200	574	2·50	1·12	
8 Sundries.	8000	1064	3	51	276	2077	7·51	1099	500	4·10	1·36	
9 Sundries.	8000	1064	3	27	309	2318	7·51	1157	524	1 42	1·00	
10 Australian, per 'Royal Charter.'	8000	..	..		239	1783	7·46	1115	..	0·49	1·71	

"The above test-trials were made at the request of the owners of the respective collieries, for the purpose of ascertaining the calorific value and peculiarities incident to each coal, as regards clinker, ash, &c. The names of the collieries or owners are purposely omitted, as the returns of any one kind of coal are never communicated to those of any other kind."—WILLIAM BALFOUR M'ALLISTER, *Foreman Boiler Maker to the Company.*

These only embraced the returns of the last nine months, and the tests were all made at the request of their respective owners, on opening new beds in their collieries. Wye Williams adds, I suppress the names of the different coals to avoid giving unnecessary offence to any of the proprietors. It will be observed that as there was no smoke from any kind of coal, and perfect combustion effected, the full calorific effect was obtained in every instance. This was also confirmed by the appearance of the furnace, as every part of the interior was made visible by means of properly-placed sight-holes, as was the case in the Newcastle experiments. These returns show the error of estimating the so-called evaporative power of the coal by reference to the water evaporated by each pound weight of the coal. We even find that the description which gives the largest return in that respect, may, in fact, be the worst adapted for steam-generative purposes, inasmuch as the time occupied is so much greater. This element of time is of the highest importance, as regards the providing an adequate supply of steam for the cylinders. Take, for instance, No. 4. There the amount of water evaporated to a lb. of coal was 10·20 lbs., yet there were but 1707 lbs. evaporated *an hour*—during the time required for the evaporation of the tank full, of 8000 lbs.—say, in all, four hours forty-one minutes. Whereas, in the case of No. 7, though there were but 8·92 lbs. evaporated *to a lb. of coal*, there were no less than 2232 lbs. evaporated *an hour*, the 8000 lbs. being evaporated in three hours thirty-five minutes. A further illustration of the importance of attending to the *mode* in which the several kinds of coal enter into combustion, as Percy has well observed, is shown in the following returns, where five kinds of coal were tested, and the temperatures in the flues and of the escaping products were both noted:—

HEAT DEVELOPED PER CHARGE OF 56 LBS. COAL, SHOWN BY THE PYROMETER IN THE FLUES INDICATIONS.—TIME, 20 MINUTES.

No. 1. Swansea.	No. 2. Newport.	No. 3. Coed Talon.	No. 4. Powell's Duffern.	No. 5. Main Depth.
740	753	1000	835	1120
750	725	1045	845	1150
760	720	1035	850	1225
765	725	1060	855	1255
775	735	1075	860	1280
785	745	1075	870	1290
795	755	1080	900	1295
805	765	1080	920	1300
825	775	1095	925	1300 max.
835	790	1095	945	1280
840	805	1095	955	1250
850	815	1100	970	1225
855	825	1100	975	1220
865	830	1100	980	1200
875	845	1110	990	1155
885	855	1120 max.	1000	1130
895	865	1110	1000	1110
905	875	1115	1005	1100
910	890	1105	1010	1075
910 max.	895 max.	1075	1020 max.	1050
20)1662·5	20)1598·5	20)2167·0	20)1871·0	20)2401·0
831°	799°	1083°	·935°	1200°
Average Waste Heat in Chimney.				
450°	450°	484°	397°	574°

In Nos. 1, 2, and 4, of the annexed Table the largest development of gas, and consequently the highest temperature (assuming that perfect combustion was realized), was at the *end of each* charge of twenty minutes (the temperatures were taken at intervals of a minute), whereas, in Nos. 3 and 5 the maximum temperatures were attained at the end of sixteen minutes and eight minutes respectively. This latter is the coal preferred by the Dublin Steam Company. Williams adds, I am sure it will be acknowledged that these tables contain much valuable information which is omitted from the official returns required by the Admiralty when steam coals are tested for them. In those returns no account is taken of the gross time employed in the evaporation of any gross weight of water; neither are we told what temperature was obtained for evaporative purposes; nor what escaped in the state of waste heat; nor how far combustion was perfect, as indicated by the presence or absence of smoke in the chimney. We see in them no indication of the use of that valuable and all-important instrument the *pyrometer*, without which it is impossible to form any correct estimate of the calorific or commercial value of any kind of coal.

Feeling so deeply the inefficiency of the tubular system as now generally adopted, I have endeavoured to substitute for it some more effective one, bearing in mind, of course, the necessity (to which I have before referred) of ensuring the direct action of the hot products of combustion upon the heating-surface. My endeavours in this respect have not been successful. I have arranged a form of tube, or rather flue, which presents a series of surfaces against which these hot products will strike at right angles, or nearly so, and consequently transmit a larger quantity of heat to the water in the boiler. As this, however, would be of comparatively small effect, unless accompanied by other material changes in the details and construction of the boiler, and the removal of the several evils already enumerated, I propose here detailing those alterations and principles, with their influence, chemically and practically, which go to the formation of a perfect boiler and its furnaces, namely:—

1stly. That in the construction of a boiler, the proportions of its several parts, in particular, its length, from the door to the back-end, should be determined by considerations based on giving effect to those processes and principles on which the combustion, chemically considered, of the constituents of fuel—solid and gaseous—depends. Without regard to this common sense view of the subject, the length of boilers is usually determined by the mere area or space allowed by the actual width of the vessel. This injudicious proceeding appears to have been adopted for the sole purpose of introducing the greatest number of boilers into the smallest possible space—the steam-generative property of a boiler being assumed to depend on the length and area of the fire-grate surface, and wholly irrespective of the chemical process of combustion to be carried on. This at once leads us to the inference that the distance between the fuel at the bridge and the tubes should never be less than from 6 to 8 ft. lineal—experience having shown that it is impossible to effect the perfect combustion of the gaseous constituents of the coal in a shorter space.

2ndly. That where the furnace-bars are above 4 ft. in length, from the dead-plate to the

bridge, and where the chamber is less in height than 2 ft. from the dead-plate to the crown of the furnace, there should always be provided the means of introducing a supplemental supply of air to the gases passing over the bridge. The mode adopted (see Fig. 884) in the Holyhead steam-packet, by a cast-iron plate with a sufficiency of half-inch orifices, has been found as successful as could be expected, looking to the great space occupied by the tubes, and the consequent absence of an adequate combustion-chamber.

3rdly. That tubes should never exceed 3 ft. in length, experience having supplied unquestionable proof of the comparative inutility, as heat-generating surface, of any greater length, while it seriously curtails the space that might otherwise be occupied as a combustion-chamber.

4thly. That the steam generated by the heat from the side and crown plates of the furnace should not be allowed to ascend through the tubes, or interfere with the steam generated from the latter, as already mentioned; but that it be directed to pass upwards through the spaces between the several separate stacks of tubes.

5thly. That the waste heated products from the several furnaces should not be directed into one common receptacle or smoke-box, as is done in the 'Great Eastern' and 'Warrior;' but that the furnaces, being set in pairs, their products should be kept in pairs, until, passing through the uptake, they arrive at the base of the chimney. The reasons and proofs which influence this arrangement are numerous, but cannot be here detailed for want of space.

6thly. Boilers should be so placed that the furnace-doors should face the fore part of the ship, by which the material draught caused by its velocity would come in aid of the direction of the air into the ash-pits, and through the apertures in the furnace-door boxes.

In reference to *Priming*, Murray observes:—"When the ebullition inside a boiler is so rapid and violent that water rises with the steam, and is carried over with it to the engines, the boiler is then said to prime. Besides the danger to the machinery which always attends this propensity, it entails a serious loss of heat, carried off by the water which boils over or is forced up the waste-steam pipes." If this be a correct description of the process of priming, the tubular system has much to answer for the evil, as being peculiarly subject to this "propensity." In consequence of the violent transmission of heat, caused by the large surface of the face-plate exposed to the direct action of the flame, as already described, there is the greatest tendency to that local and violent ebullition by which the liquid matter is forced upwards, and which is no doubt the main source of priming. It may here be observed, however, that the idea of a "serious loss of heat carried off by the water," is erroneous, and arises from the supposition of the water being heated, and having absorbed a given quantity of heat. Now, so long as the water particles retain their liquid form, they have taken up no heat, and can, therefore, carry none along with them. Williams here remarked, "I am sorry to have to refer to a work of my own, but I have taken so much pains to establish this doctrine in my recent work, 'On Heat in its relation to Water and Steam, embracing New Views of Evaporisation, Condensation, and Explosion,' that I trust I shall be excused for referring to it here." The true loss and injury occasioned by the water being carried over in the process of priming, arises—1st. From the liquid particles taking up heat from the inside of the cylinder into which it is carried, and by which a cooling effect is produced; 2nd. From the particles carrying a large portion of the salt and other impurities with which the water may be impregnated, and which to a considerable extent produce an injurious effect upon the valve-facings. "Priming," Mr. Murray adds, "may arise from a variety of causes; but the usual one is a too contracted steam-space over the water of the boiler. For where the reservoir of steam from which the engines are supplied is very small, there must be constant pulsations of pressure in the boiler; and each time that the surface of the boiling water is relieved of a certain amount of pressure by the rapid withdrawal of a cylinderful of steam, it boils up with great violence." This is unquestionably true. It must not, however, be forgotten that the prevailing practice of using higher pressure, and cutting it off, for the sake of *expansion*, greatly increases, if it does not produce, this very serious evil of a constant pulsation of pressure. We cannot, therefore, have the benefit of the expansion principle carried, as it now is, to so great an extent, without the concurrent evil of having the liquid matter carried even into the cylinder by these frequent pulsations. This is peculiarly the case where the cylinders are large and the expansion process is carried out to a great extent.

I must, however, insist on the fact, that the violent local ebullition, peculiar to the tubular system, produced immediately behind the face-plate, as already explained, is the main source of the evil of priming. This is well exemplified in the case of new boilers, and on their first trial. The face-plate being then clean, both inside and outside, and the water-spaces being fully charged, and without obstruction to the water's circulation, the transmission of heat through that plate is at its maximum; and the generation of steam greater there then than it ever can be afterwards. The violent ebullition immediately behind the face-plate is far in excess of what can be conceived by those who have not had the means of personal inspection. None but an eye-witness could have an adequate idea of this local action, or of the mass of water thrown up immediately behind the face-plate, with the spray driven off in large quantities; while the other parts of the water-surface are comparatively tranquil, or exhibiting but the ordinary effect of moderate boiling. It was this fact which first drew my attention to the action of the face-plate. I observed that the boilers of the 'Warrior,' like those of too many other vessels, were reported to have been exposed to priming on their first trial; and when I look at the immense extent of face-plates in which the 4400 tubes are inserted, I cease to wonder at the violence of the local ebullition, or at the priming which resulted from it. As the continued use of a boiler causes a considerable diminution of water-space in the rear of the face-plate, by the incrustation which is there rapidly produced, on account of the great heat to which it is exposed, we can readily explain the subsequent diminution of priming when the boiler has been some time in use.

Hitherto we have had no sufficient explanation, chemically or otherwise, of the cause of priming. When, however, we examine closely the act of ebullition, we shall have no difficulty

in comprehending the *rationale* of the process by which the water particles are thus separated and thrown up, and carried by the force of the current out of the boiler. Each bubble formed in a liquid is a spherical or semi-spherical mass of aëriform matter. In the case of boiling water it is of *pure steam* enclosed in a spherical envelope of liquid particles, formed by the repellent force and divergent action of the several steam particles. The *liquid* particles, on the other hand, by reason of their individual attraction and cohesion, sustain that continuity which forms the envelope. When each globe or envelope bursts, the liquid particles of which it is composed are scattered, and, as it were, exploded, and then carried forward to the cylinders. Looking, then, to the violence of ebullition, and the quantity of liquid spray thrown up immediately behind the face-plate, and in no other place, we are enabled to appreciate the source and nature of priming, and the part which the tubular system and its face-plate act in producing this result. The pulsations, then, spoken of by Murray, are not by any means the main cause of priming, but are merely secondary to that violent and local ebullition so peculiar to the action of the face-plate. We see this result of ebullition in the common operation of distilling water for chemical purposes. When the distillation is carried on rapidly, and the water is made to boil violently, the so-called distilled water is found impure to such an extent as to require a repetition of the process, and a double or treble distillation. To obtain pure water from the still, the heat should not be allowed to exceed 200°, when ebullition begins.

On the subject of *Superheating* there seems to be much confusion. The term "superheating the steam" necessarily implies an increase in its temperature. When, however, we examine the operation, we find that, practically, we merely increase the quantity of available steam. Steam, as an elastic fluid, resembles air as regards the difficulty of increasing its temperature; so that anything to be gained in this respect from the action of the heated products passing to the chimney, as waste heat, must be very insignificant. In truth, all we do by the process is to vaporize the liquid particles, which, more or less, always accompany the steam generated from water at what is called the boiling-point. If a given quantity of steam in the boiler contains, say 10 per cent. of liquid particles, their conversion into steam is of equal value with the vaporization of any other 10 per cent. of the water in the boiler. In addition, however, it has the further advantage of relieving the cylinders from the presence of so much liquid matter. In high-pressure engines, as in locomotives, this is not of such importance, inasmuch as the liquid particles are driven off with the steam as each cylinderful is discharged. In the case of *condensing* engines, however, the advantage arising from the absence of liquid matter, and what is termed dry steam, is considerable.

"All boilers," Murray observes, "are subject to the loss of a certain quantity of heat contained in the water which passes off with the steam in the shape of a fine spray. When much of this mixes with the steam, the latter is said to be 'wet'; but it is believed that all steam raised in the ordinary way is thus more or less charged with water in a state of fine subdivision." This has already been considered when speaking of priming. Murray goes on to say:—"To evaporate" (more correctly speaking, to *vaporize*) "and utilize this water is one of the principal advantages of surcharged or 'superheated' steam." He might have gone further, and have said that this is the *sole* advantage gained by this much-extolled process. That this is even Murray's opinion may be assumed from the following brief, and, I believe, just summary, namely:—"The very high rates of economy are shown by those boilers which were previously the worst to keep steam with, and which required very hard firing to do so; those addicted to priming and wet steam rank next in apparent economy; while those boilers that show the least were originally the best specimens of their class." This at once raises the question whether it would not be better to have the boilers so constructed that they should have no spare heat to be so applied; for whatever heat is so applied would have been more economically and efficiently employed in generating steam in the first instance, rather than in being allowed to escape, as waste heat, for the employment of which this superheating process, and the other process of heating the feed-water, have been invented. Whatever degree of success accompanies either of these processes will, in fact, be in the ratio of the waste heat; that is, in proportion as the boiler is deficient in the legitimate application of the heat generated by the combustion of coal. Thus, the more imperfect are the boiler and its furnaces in promoting perfect combustion, and thus realizing the full calorific power of the fuel, and in applying the heat so generated, the greater will be the apparent advantage of heating the steam of the feed-water.

Robert Murray being selected from among many modern engineers who entertain similar views respecting boilers, it is only right to add R. Murray's reply. Writing to the secretary of the Inst. of N. A., Murray said:—"Having been unable to attend the last meeting of the Institution of N. A., I am glad to be allowed this opportunity of replying very briefly to Mr. Wye Williams's remarks upon certain portions of a paper of mine, read before the Institution in the spring of 1860. While doing so, I would wish to express my hearty appreciation of Mr. Williams's long and valuable labours in the peculiar branch of engineering science to which he has so ardently devoted himself; but, at the same time, I must confess to a doubt whether he is not riding his hobby rather too fast. It is my lot to see many pet contrivances and fondly-cherished theories sent off from this port of Southampton on a cruise into the wide world; and of these, when separated from the fostering care of their parents, very few indeed ever live to come back. This sad spectacle, in place of enlarging our sympathies, tends I fear to make us practical men only the more hard-hearted and unbelieving. I admit, however, that a little poking by such men as Mr. Wye Williams is good for us. I shall now attempt to meet some of Mr. Williams's objections.

"With regard to the much-vexed question of 'smoke-burning,' I still maintain that in the furnaces of a marine boiler 'it is not always an economical process;' and further, that 'considerable caution is necessary for the due regulation of the quantity of air to be admitted for this purpose.' It is of course apparent to every one, that the furnace demands a large quantity of

atmospheric air at each recurring period, when the fresh charge of coal is undergoing the process of distillation, and therefore parting with its gaseous constituents. This state of the furnace, however, lasts for only two or three minutes out of every ten; and if the rush of cold air were to be continued after the fire has burnt clear, and there is only incandescent carbon on the bars, a most damaging effect would be produced by the cooling of the flues and tubes. It becomes, then, a practical question, whether the quantity of air to be admitted can be readily and properly adjusted to the condition and requirements of the fuel in the furnace. That with an experimental boiler worked by trained stokers, either on shore, or on board ship, this can be done so as to show a high degree of economy, no engineer will doubt; but the question still remains, Can we place sufficient dependence upon the ordinary fireman to be found on board a steamer, as to leave it in their power to inflict a serious injury upon the boilers by their stupidity or neglect; or will it not be preferable to adopt some simple and fixed arrangement for this purpose, which will not be dependent for its efficacy upon the precarious attention of the stokers? This may be done to some extent by self-acting apparatus; but whenever such has been fitted on board a steamer, it has been (so far as my experience goes) invariably abandoned after a few months' trial. It would appear, in fact, that the usual conditions of the stoke place of a sea-going steamer are incompatible alike with any great amount of discriminating attention to be expected from the men, or with the satisfactory working of a piece of nice mechanism left in their charge. There can, I think, be no objection to admitting a *small* and fixed quantity of air through a perforated plate behind the fire-bars (as shown in Williams's woodcut, Fig. 884), if this be done judiciously. The danger in such a case is, that the neighbouring plates may suffer harm from being one minute intensely heated as by the flame of a blow-pipe, and the next minute chilled by a cold blast after the flame has been expended, the continual expansion and contraction thus induced tending to weaken the plates by throwing iron-scale off their surface. It is therefore, perhaps, the safer plan to keep by the more usual expedient of admitting the air through a number of small holes punched in the fire-doors, say ⅜-in. holes at the distance of 1½ in. from centre to centre, which appears to answer every purpose, the door itself being slightly opened when more air is wanted. The bars must at the same time be kept covered with a *thin* fire, through which the air can penetrate, and not smothered with coals as shown in Mr. Williams's woodcuts.

"As to the alleged deficiency of absorbent power in the tube-surface of a marine boiler, there can be no question but that Mr. Williams's statements and conclusions demand the most careful and anxious consideration. I confess myself so far a convert to his views, that I would be glad to see the tubes curtailed in length to such an extent as to admit of a considerably larger space than is usually allowed between the ends of the bars and the tube-plate. That the first portion of the tubes should be so much more effective than the rest may, I think, be explained by supposing that the flame penetrates through them to this distance only, becoming then extinguished by the reduction of temperature in the tubes, in the same way that it cannot pass through the meshes of the wire gauze of the miner's lamp. That the remainder of the tubes should not absorb more heat from the gases in their transit, is certainly a very remarkable and unlooked-for result. The use of tubes of not less than about 3½ in. diameter seems preferable, as allowing the flame to penetrate further through them.

"While speaking of 'priming,' Mr. Williams remarks that my expression of a 'serious loss of heat being carried off by the water' is 'erroneous.' The extent of this loss is evidently just so much caloric as was necessary for raising the ejected water from the temperature of the feed to that of the water in the boiler.

"Lastly, with regard to superheated steam, it is now pretty well understood that with a temperature of from 280° to 300° Fahr. in the steam-pipes we have all the advantages of which the process is capable without endangering the valves and packings of the engines. I must differ from Mr. Williams, however, in thinking that its 'sole' advantage is the vaporization of the watery particles contained in the steam, as I think we derive an almost equal advantage from the saving of condensation in the pipes, ports, and cylinders."

Mr. C. Wye Williams, writing to the secretary respecting the above remarks of Mr. Murray, said:—'In reference to Mr. Murray's additional remarks, I have only to express my belief that his objections are severally and substantially answered in the extracts I have given from the report of Messrs. Armstrong, Richardson, and Longridge, on the proceedings at Newcastle (page 440). His remarks on the admission of air and 'smoke burning' seem to be the result of an oversight, on his part, as to what my plans and recommendations really are. My regret at this is the greater, as he has himself fully absolved me from the charge of suggesting speculative remedies, when he adds:—'I see no objection to admitting a small and fixed quantity of air through a perforated plate behind the fire-bars, as shown in Mr. Williams's woodcut, Fig. 884.' Again, Mr. Murray says:—'It is, perhaps, the safer plan to keep by the more usual expedient of admitting air through a number of small holes in the fire-doors, which appears to answer every purpose.' Had Mr. Murray looked further he would have found that this 'safer plan,' which 'answers every purpose,' is identically what I adopted under my patent of 1838, and was that exclusively used by me at the Newcastle experiments, which lasted twelve days, the claim of the patent being, 'The use, construction, and application of the perforated air-distributor, by which the atmospheric air is more immediately and intimately blended with the combustible gases generated in the furnace.'

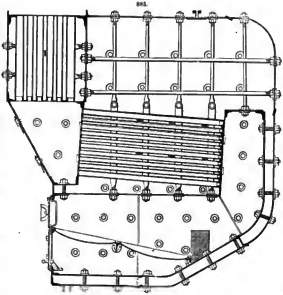
"As to the deficiency of the heat-transmitting power of tubes, which it was the main purpose of my paper to describe, Mr. Murray says all that was necessary in confirmation of my views, and in giving them the benefit of his concurrence, when he adds:—'As to the alleged deficiency of absorbing power in the tube-surface, there can be no question but that Mr. Williams's statements demand the most careful and anxious consideration. I confess myself so far a convert to his views that I would be glad to see the tubes contracted in length to such an extent as to admit of a considerably larger space than is usually allowed between the ends of the bars and the tube-plate.' If this be done, it will remove one of the impediments, both to the full combustion

of the furnace-gases, and the increased evaporative power of the boiler. On the whole, then, it appears that, so far from there being any essential difference between Mr. Murray and myself, we are substantially in accord on all essential points."

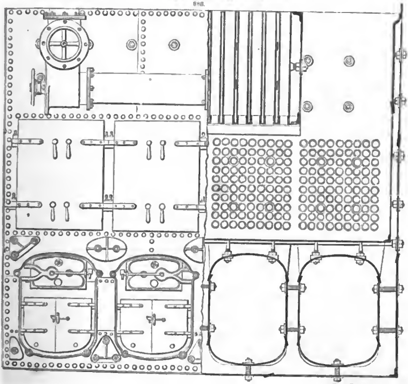
We now come to the present practice of engineers, by which different descriptions of boilers are constructed and arranged to suit various purposes. How far these numerous forms and combinations fulfil the necessary requirements, the engineer will, it is presumed, be able to decide, from the accurate experiments, abstract reasoning, and practical results which we have adduced.

Marine Boilers.—Fig. 885 shows an example of the high-type modern marine boiler, as designed by N. P. Burgh, and illustrated in his

885.



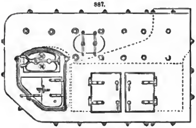
886.



practical work on Marine Engineering, to which we are indebted for many of our examples of marine boilers. The fire-box and combustion-chamber are partially separated by a brick bridge. The tubes have a slight rake inclining upwards at the smoke-box end, this end being the final evaporator. The vertical tubes in the upper portion of the smoke-box are for superheating. The fire-bars are inclined towards the inner extremities for two purposes, the one to assist the action of stoking or agitating the fire, and the other to accelerate the draught—it being remembered that the greater portion of the draught enters below the bars. Fig. 886 shows an enlarged front elevation of the same, half complete and half in section.

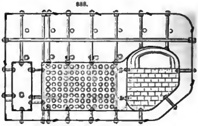
Figs. 887, 888, 889, show an end elevation, sectional plan, and sectional elevation of the boilers fitted in H.M.S.S. 'Vigilant,' 'Wanderer,' and 'Osprey,' by Maudslay, Sons, and Field. The disposition of the boilers in the hull is represented by the elevations, the plan referring to only one

887.



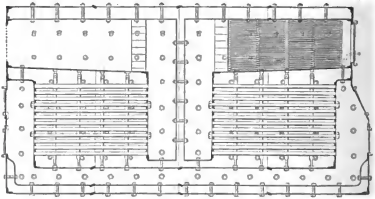
End elevation.

888.



Sectional elevation.

889.



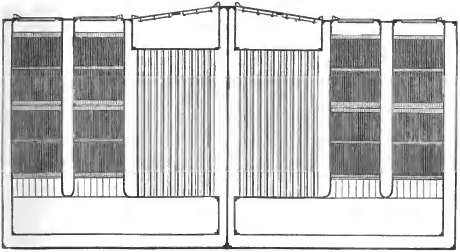
Sectional plan.

boiler. The fire-boxes are fore and aft of the shell at the side. The combustion-chambers, one to each grate, are at right angles with the fire-boxes; the tubes are arranged in a line with and outside each fire-box, thus forming a return action. A longitudinal flue is introduced, extending throughout the length of the boiler, so as to render the final uptake common to the smoke-boxes. On referring to the sectional elevation, it will be seen that this flue is the same height as the smoke-box, a divisional water-space causing a complete separation. The fire-box is contracted at the base-line, also the side and bottom of the shell are angularly connected. This form of construction is due to the beam of the hull for which the boilers were designed.

The details are:—Two boilers of 100 H.P. collectively; length of shell, 19 ft. 4 in.; width of one shell, 9 ft. 6 in.; height of shell, 5 ft. 10 in. There are four fire-grates, each grate being 6 ft. 4 in. long by 2 ft. 10 in. wide. The fire-box is 3 ft. 6 in. deep at each end. 192 of the tubes are 6 ft. 6 in., and 192 6 ft. in length. The total number of tubes is 384, each tube being $2\frac{1}{4}$ in. outside diameter.

Fig. 890 represents a boiler with tubes, made by Maudslay, Sons, and Field, for H.M.S.S. 'Mutine' and 'Chameleon.' The boiler is of 66 H.P.; the shell is 9 ft. 8 in. long, 18 ft. 4 in. wide, and 7 ft. 6 in. high. There are four grates, each grate being 5 ft. 10 in. long by 2 ft. wide. The fire-box is 3 ft. 10 in. deep. Total number of tubes 262, each tube being 6 ft. long and $2\frac{1}{4}$ in. outside diameter. There are two grates to each cluster of tubes, placed near the outer side of the shell. The combustion-chamber is at right angles with the grate. The tubes are placed in the centre between the fire-boxes. The smoke-boxes are at the boiler-front between the inner fire-boxes.

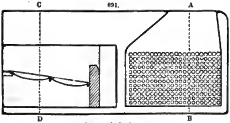
890.



Sectional plan.

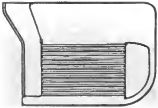
Figs. 891, 892, 893, 894, show elevation, plan, and sections of the two boilers of H.M.S.S. 'Reindeer' and 'Perseus,' by J. and G. Rennie. They are of 130 H.P. Length of shell, 16 ft.; width, 10 ft. 6 in.; height, 7 ft. 6 in.; six fire-grates, 5 ft. 6 in. long by 2 ft. 10 in. wide; fire-box, 4 ft. 6 in. deep; 528 tubes, each tube being 6 ft. long and 2½ in. outside diameter.

891.



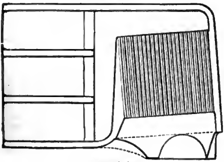
Sectional elevation.

892.



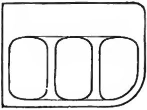
Section at A, B.

893.



Sectional plan.

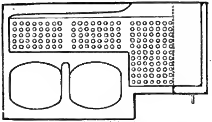
894.



Section at C, D.

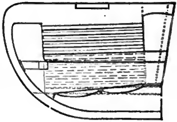
Figs. 895, 896, show elevation and section of the boilers made by J. and G. Rennie for S. S.S. 'General Murillos' and 'General Victoria.' There are four boilers, of 200 H.P. collectively. Each shell is 12 ft. long, 10 ft. wide, and 7 ft. high. There are eight grates, each grate being 5 ft. 9 in. long by 3 ft. wide. The fire-box is 3 ft. deep in front, and 2 ft. at back. There are 628 tubes, 6 ft. long and 2½ in. outside diameter.

895.



Sectional elevation.

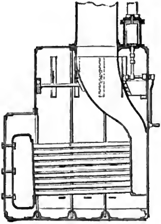
896.



Transverse section.

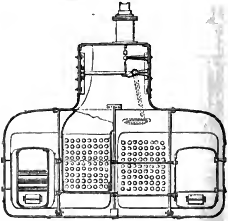
Figs. 897, 898, show the tubular boiler made by James Watt and Co. for the Bombay Steam Navigation Company. It is of 30 H.P. The shell is 7 ft. 1 in. long, 11 ft. wide, and 8 ft. 6 in. high. It has two grates, 4 ft. 9 in. long and 2 ft. 2 in. wide. The fire-box is 3 ft. deep. Number of tubes 144, each tube 4 ft. 11 in. long, 2½ in. outside diameter. The doors seen under the grate at the back, Fig. 898, are for the admission of air beyond the bridge, a suitable framework being fitted in the fire-box. The gear shown by the dotted lines and in the dome relates to the safety-valve. Fig. 897 shows the combustion-chamber, smoke-box, and uptake, in section. It will be seen that the tubes connecting the combustion-chamber and smoke-box are at an incline; this is for the purpose of accelerating the draught. The uptake is curved and surrounded by the steam; this renders partial superheating attainable without extra detail or expense.

897.



Sectional elevation through A, B.

898.



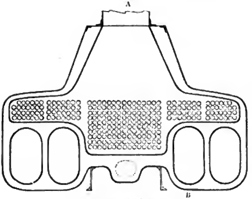
Transverse sectional elevation.

Figs. 899, 900, show the boilers made by James Watt and Co. for the S.S. 'Tyrsaad.' They are of 120 H.P. The shell is 8 ft. long, 15 ft. wide, and 10 ft. high. There are eight grates, 7 ft. long and 2 ft. wide. The fire-box is 3 ft. deep in front, and 3 ft. 3 in. deep at back. There are 520 tubes, each tube being 5 ft. 8 in. long and 2½ in. outside diameter.

Figs. 901, 902, 903, 904, represent the two boilers made by James Watt and Co. for H.M.S. 'Hornet.' They are of 100 H.P. Length of shell, 16 ft. 6 in.; width of one shell, 9 ft. 6 in.; height of shell, 7 ft. 6 in. Six grates, each grate 5 ft. 3 in. long by 2 ft. 4 in. wide. The fire-box is 3 ft. deep in front, and 3 ft. 6 in. at back. There are 440 tubes, each 5 ft. 6 in. long and 2½ in. outside diameter.

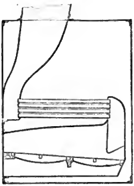
The tubular boiler invented by Edward N. Dickerson is shown in Fig. 905. It has two series of tubes, W and S, through one of which series the water passes, and upon the exterior of which

899.



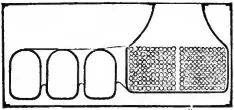
Transverse sectional elevation.

900.



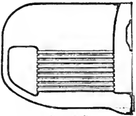
Section through A, B.

901.



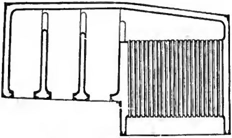
Sectional elevation.

902.



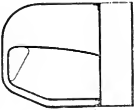
Section at A, B.

903.



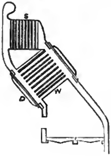
Sectional plan.

904.

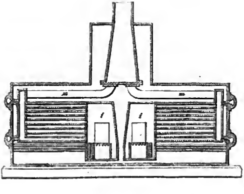


Section at C, D.

905.



906.

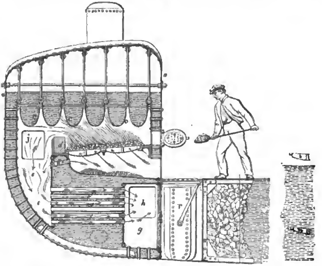


the heated products of combustion impinge, while the steam on its passage to the outlet is made to surround and envelop the other series through which the products of combustion are made to pass, thus superheating the steam. The water-tubes of this boiler are so arranged that by removing doors or plates D, both ends of the tubes may be reached and cleaned without going into the boiler.

Fig. 906 refers to the boiler invented by William Mont Storm. The boiler consists of a cylindrical horizontal shell, in the centre of which are situated two fire-boxes separated by a water-space. The smoke-boxes are situated within the water-space, with the pipes *m*, *m* for circulating the smoke to the uptake. Flues are provided for conveying air to the furnace, which run parallel with the generating tubes; and a water-head is formed in each end of the boiler for affording access to the outer ends of the tubes. This water-head is connected with the boiler by circulating pipes, so that it is made to act as a generator of steam as well as a water-heater. The fire passes right and left through the flues or tubes to the chambers *i*, *i*, and thence through its proper conduit to the uptake.

Fig. 907 is an elevation in section of the marine steam-boiler of that ingenious inventor and engineer, Thomas Dunn. *a* is the outer shell of the boiler; *b*, the fire-grate, and *c*, the roof of the fire-box, which is formed of semi-elliptical plates riveted together at their edges, thereby producing a corrugated surface against which the products of combustion impinge; these corrugations give a larger heating-surface to the fire-box and increase its strength. Beyond the fire-grate *b* is the bridge *d*, over which the products of combustion pass to the down-flue *e*, then through the tubes *f*

907.

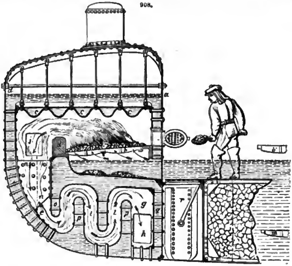


forming the multitubular part of the boiler, and then into the chamber *g* which communicates by means of the flue *h* with the chimney or funnel. Under the bridge *d* a few short tubes *d'* are inserted to admit air into the down-flue *e* for the purpose of igniting the inflammable gases passing over the bridge *d*. The flue *j* near the bridge is only opened when the fires are just ignited; but if, owing to the leaking of the vessel, the water should come in and close the lower flue *h*, the flue *j* may be opened so as to keep the engines going until the water rises in the vessel sufficiently to extinguish the fires. The grate-bar *m* is shown in about the position of the fire-grates in marine boilers of the ordinary construction, and the grate-bar *b* above it indicates the level of the fire-grate in Dunn's boiler.

Fig. 908 is a section of another of Dunn's marine boilers. In this instance the roof of the fire-box is made of corrugated plates *c* stayed longitudinally and vertically, and the water-partitions *n*, shown in section in Fig. 909, are placed in the down-flue *e* to absorb a portion of the heat from the products of combustion in passing to the up and down flues *l*, which are formed by the water-partitions *o*, projecting downwards from the central portion of the boiler, and the partitions *p* projecting upwards from the lower part of the boiler. The chamber *g* and the flues *h* and *j* are similar to those above described in reference to Fig. 907. In this boiler the outer side of the chamber *g* is formed by the water-partition *q*, and consequently all the flues and lower portions of the boiler are perfectly water-tight, so that in case of the leaking of the vessel the boiler may be kept in full work until the water rises to the level of the fire-grate *b*. In both the marine boilers shown in Figs. 907, 908, the fire is applied near to the surface of the water, and in a most advantageous position for rapidly generating steam; the ashes and cinders are collected in the buckets *r*, and the direction of the products of combustion is indicated by the arrows.

Fig. 910 represents a modification of the marine boilers shown in Figs. 907, 908. In this boiler the heating-surface is increased, and the circulation promoted by the two sets of tubes M and N

908.



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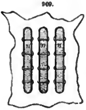

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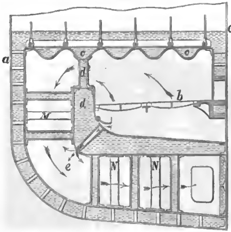
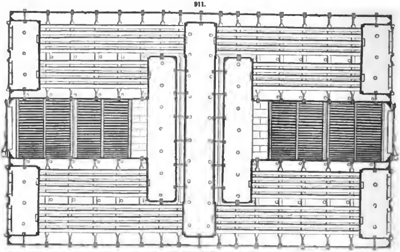


placed in the flue *e*. The bridge *d* is made to contain water, and it is connected to the corrugated roof *c* by pipes d^2.

Figs. 911, 912, show an elevation and plan of two boilers designed by N. P. Burgh for a gun-boat. They are of 100 H.P. collectively. The shell is 19 ft. 9 in. long, each shell 12 ft. wide and 5 ft. 9 in. high. There are four grates, 6 ft. long and 3 ft. wide. The fire-box is 3 ft. deep. There are 780 tubes, 400 being 5 ft. 9 in., and 380 7 ft. 6 in. long; outside diameter of each tube, 2¼ in.

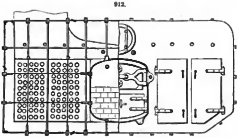
The boilers made by Mandslay, Sons, and Field, for H.M.S.S. 'Ajax' and 'Edinburgh,' are shown in plan, Fig. 913. In each ship there are two, of 450 H.P. collectively. The shell of each boiler is 34 ft. 6 in. long, 15 ft. 6 in. wide, and 9 ft. 10 in. high. There are twelve fire-grates, each grate 6 ft. 4 in. long and 3 ft. wide. The fire-box is 3 ft. 6 in. deep in front, and 4 ft. 2 in. at back. Number of tubes, 1506; each tube 4 ft. 10 in. long, 2¼ in. external diameter.

911.



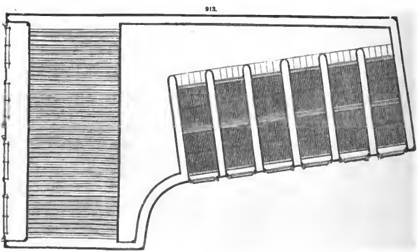
Sectional plan.

912.



Elevation, half in section, half complete.

913.



Figs. 914, 915, exhibit elevations of the boiler designed by N. P. Burgh for a steam yacht. It is of 25 H.P. The shell is 11 ft. 6 in. long, 7 ft. wide, 7 ft. high; one fire-grate, 6 ft. long, 2 ft. 9 in. wide; fire-box, 2 ft. 9 in. deep. Number of tubes, 72; each tube 8 ft. long and 2½ in. outside diameter.

E. Humphrys' marine boiler is shown, Figs. 916, 917. The uptake is constructed in such a manner that a number of vertical tubes may be placed in it, the uptake forming part of the main boiler. The vertical tubes serve as a superheating apparatus, and render unnecessary any pipes or valves for conducting the steam to the superheater.

Fig. 917 shows the tubes and smoke-box. Directly above the tubes a plate is fastened, and another plate is placed near the roof, the plates being connected by the vertical tubes and stays. The passage of the steam is indicated by the arrows.

The boilers represented in Figs. 918 to 921 are fitted in H.M.S. 'Oberon,' 260 H.P., and were designed by Capt. A. A. Cochrane and at Woolwich Factory respectively. The length of shell in Capt. Cochrane's boiler, Figs. 918, 919, is 12 ft.; width of shell, 11 ft. 6½ in.; number of steel tubes, 915; length of steel tubes, 3 ft. 3 in.; outside diameter of steel tubes, 1¾ in.; actual weight of boiler, 20 tons 7 cwt.; actual weight of water, 12 tons 8 cwt. 1 qr.

		Total.	Each nominal H.P.	To each foot of Grate.
Heating-surface in tubes	sq. ft.	1310·54	10·08	18·25
" " furnaces, &c.	"	337·83	2·6	4·71
Total heating-surface	"	1648·37	12·68	22·96
Area of fire-grate	"	71·79	·55	..
Capacity of combustion-chamber	cub. ft.	157·2	1·21	2·19
Area at throat of "	sq. in.	2146·37	16·51	30·0
" between close tubes	"	1942·0	15·0	27·04
" under trap or water-space	"	2099·5	16·15	29·2
" between smoke-box door and water-space	"	1799·0	13·83	25·05
" at mouth of uptake	"	1728·0	13·3	24·0

Capacity of boiler, 1460·5 cub. ft.; capacity for water, 444·78 cub. ft.; capacity for steam, 315·6 cub. ft.

The length and width of shell of the boiler made at Woolwich Factory, Figs. 920, 921, are the same as that shown in Figs. 918, 919. The height of the boiler is 12 ft. 2½ in.; number of brass tubes, 394; length of brass tubes, 6 ft. 6 in.; outside diameter of brass tubes, 2½ in.; actual weight of boiler, 21 tons 13 cwt. 8 lbs.; actual weight of water, 14 tons 19 cwt. 3 qrs.

		Total.	Each nominal H.P.	To each foot of Grate.
Heating-surface in tubes	sq. ft.	1674·5	12·88	22·08
" " furnaces, &c.	"	234·0	1·8	3·08
Total heating-surface	"	1908·5	14·68	25·16
Area of fire-grate	"	75·81	·58	..
Capacity of combustion-chamber	cub. ft.	55·18	·42	·727
Area at throat of "	sq. in.	2144·0	16·5	28·3
" through tubes	"	1564·18	12·03	20·63
" at mouth of uptake	"	1728·0	13·3	22·8

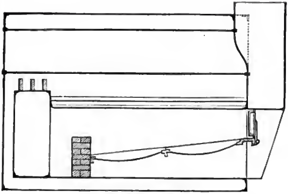
Capacity of boiler, 1460·5 cub. ft.; capacity for water, 537 cub. ft.; capacity for steam, 369 cub. ft.

The boilers for H.M.S. 'Audacious,' 800 H.P., are made on two plans, one by Ravenhill, Hodgson, and Co., and the other by Capt. A. A. Cochrane. Figs. 922, 923, 924, show the boiler by Ravenhill, Hodgson, and Co. The number of tubes is 409; length of tubes, 6 ft. 7 in.; outside diameter of tubes, 3 in.; estimated weight of boiler, 22 tons 5 cwt.; estimated weight of water, 14 tons 5 cwt. 2 qrs.

		Total.	Each nominal H.P.	To each foot of Grate.
Heating-surface in tubes	sq. ft.	2208·6	16·56	25·175
" " furnaces, &c.	"	304·78	2·28	3·47
Total heating-surface	"	2573·38	18·85	28·65
Area of fire-grate	"	87·725	·65	..
Capacity of combustion-chamber	cub. ft.	105·43	·8	1·2
Area at throat of " ..	sq. in.	3560·0	26·7	40·58
" through tubes	"	2429·0	18·22	27·69
" at mouth of uptake	"	1980·0	14·85	22·57

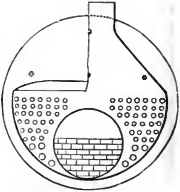
Capacity of boiler, 1898 cub. ft.; capacity for water, 519·68 cub. ft.; capacity for steam, 483·25 cub. ft.

914.



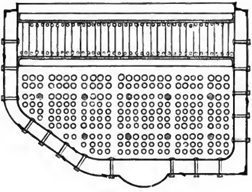
Longitudinal sectional elevation.

915.



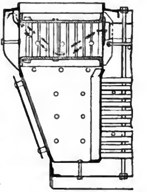
Transverse sectional elevation.

916.



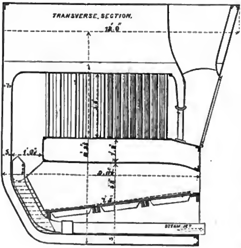
Sectional elevation.

917.

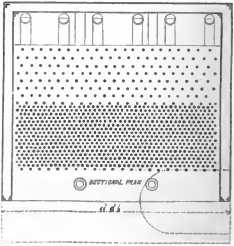


Transverse section.

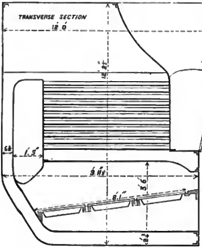
918.



919.



920.



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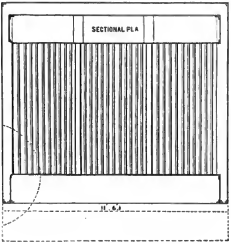

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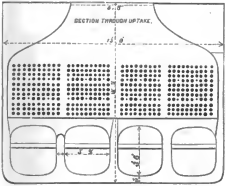
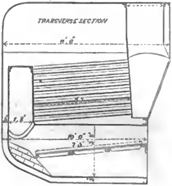
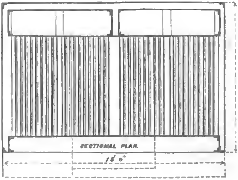


923.



924.

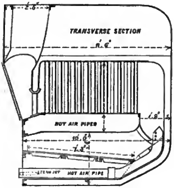


Figs. 925, 926, 927, exhibit Capt. Cochrane's plan. The particulars are:—Number of steel tubes, 870; length of steel tubes, 3 ft. 6 in.; outside diameter of steel tubes, $1\frac{3}{8}$ in.; estimated weight of boiler, 24 tons 2 qrs.; estimated weight of water, 12 tons 8 cwt. 2 qrs.

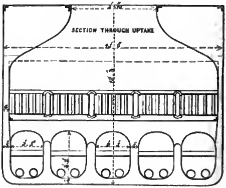
		Total.	Each nominal H.P.	To each foot of Grate.
Heating-surface in tubes	sq. ft.	1395·44	10·5	15·9
„ „ furnaces, &c.	„	513·19	3·84	5·85
Total heating-surface	„	1908·63	14·34	21·75
Area of fire-grate	„	87·725	·65	..
Capacity of combustion-chamber	cub. ft.	282·0	2·1	3·21
Area at throat of „	sq. in.	2905·0	21·7	33·11
„ between close tubes	„	3192·0	23·2	36·4
„ under trap or water-space	„	2728·0	20·4	31·1
„ between smoke-box door and water-space	„	2898·0	21·7	33·0
„ at mouth of uptake	„	2016·0	15·2	22·98

Capacity of boiler, 1898 cub. ft.; capacity for water, 445·3 cub. ft.; capacity for steam, 483·25 cub. ft.

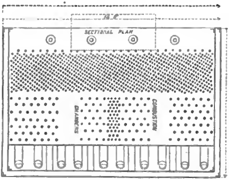
925.



926.



927.

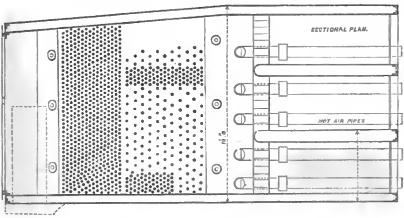


H.M.S. 'Chanticleer,' 200 H.P., is fitted with boilers designed by Capt. Cochrane and by the Government Factory at Woolwich respectively. Figs. 928, 929, 930, represent those by Capt. Cochrane. Number of steel tubes, 929; length of steel tubes, 2 ft. 6 in.; outside diameter of steel tubes, 1¼ in.; actual weight of boiler, 18 tons 18 cwt. 2 qrs. 18 lbs.; actual weight of water, 8 tons 11 cwt. 22 lbs.

		Total.	Each nominal H.P.	To each foot of Grate.
Heating-surface in tubes	sq. ft.	758·6	10·53	15·6
" " furnaces, &c.	"	241·89	3·35	5·0
Total heating-surface	"	1000·49	13·88	20·6
Area of fire-grate	"	48·37	·67	..
Capacity of combustion-chamber	cub. ft.	158·7	2·204	3·2
Area at throat of "	sq. in.	2160·0	30·0	44·66
" between close tubes	"	1545·0	21·45	32·15
" under trap or water-space ..	"	1486·0	20·64	30·72
" at mouth of uptake	"	1053·0	14·62	21·77

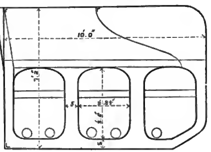
Capacity of boiler, 1384·87 cub. ft.; capacity for water, 306·7 cub. ft.; capacity for steam, 454·5 cub. ft.

928.

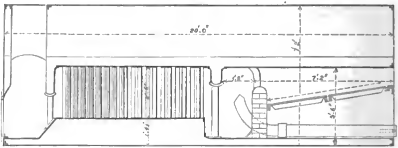


929.

TRANSVERSE SECTION



930.

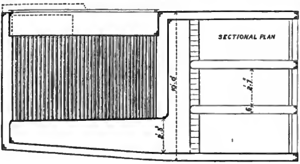


Figs. 931, 932, 933, show the Woolwich Factory boilers. The number of brass tubes, 337; length of brass tubes, 5 ft. 6 in.; outside diameter of brass tubes, 2¼ in.; actual weight of boiler, 19 tons 2 cwt. 3 qrs. 8 lbs.; actual weight of water, 11 tons 8 qrs. 7 lbs.

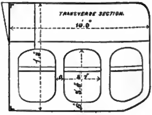
		Total.	Each nominal H.P.	To each foot of Grate.
Heating-surface in tubes	sq. ft.	1213·2	16·84	26·08
" " furnaces, &c.	"	176·39	2·45	3·8
Total heating-surface	"	1389·59	19·29	29·88
Area of fire-grate	"	46·51	·646	..
Capacity of combustion-chamber	cub. ft.	121·84	1·69	2·62
Area at throat of "	sq. in.	1075·0	14·93	23·11
" through tubes	"	1337·8	18·58	28·78
" at mouth of uptake	"	888·0	12·33	19·1

Capacity of boiler, 1384·87 cub. ft.; capacity for water, 395·7 cub. ft.; capacity for steam, 454·5 cub. ft.

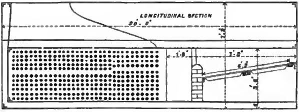
931.



932.

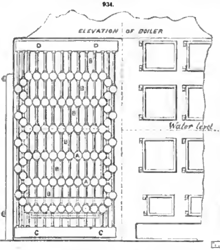


933.

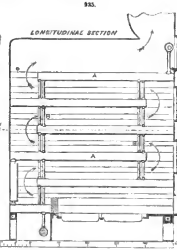


Stationary Boilers.—The boiler shown in Figs. 934, 935, was designed by A. W. Williamson and L. Perkins for very high pressure steam with great expansion. It supplies steam to an engine of 60 H.P., which works at a pressure of 500 lbs. to the square inch.

934.



935.



The boiler consists of a number of horizontal straight wrought-iron tubes A, welded at the ends, and connected with one another by smaller vertical pipes B. These tubes contain the water to be evaporated, and the steam, whilst the fire is outside them. It is essential that the larger tubes be horizontal or nearly so, and that each of them be connected to the next tube by means of two of the connecting-pipes. The boiler contains five layers of the larger tubes of 2¼ in. internal and 3 in. external diameter; the connecting-pipes are ⅞ in. internal and 1⅜ in. external diameter. In working, the water-level is in the middle layer of tubes, as shown by the dotted line in Figs. 934, 935; it remains free from the violent undulations which occur frequently in boilers where the internal space is not divided off. It is probable that a circulation establishes itself in the water, which rises with the bubbles of steam through the vertical connecting-pipe at one end of the tube, and descends by itself through that at the other. The gases from the fire pass backwards and forwards between the layers of tubes, as shown by the arrows in Fig. 935, and remain long enough in contact with them to allow of a very good absorption of the heat. In another similar boiler used for some time, there were eight layers of tubes above the fire. The boiler is thus made up of a number of vertical subdivisions arranged side by side, each containing five to eight parallel tubes. The several sections are all connected together at the bottom, by means of a cross tube C, with connecting-pipes to each section, through which the water finds the same level in all the sections. The steam is taken off through a similar cross tube D at the top of the boiler, with a connecting-pipe to the highest tube of each section. All the sections are proved with water pressure up to 3000 lbs. the square inch.

The boiler has about 12 sq. ft. of grate-surface, but the total area of the air-spaces between the bars does not amount to more than is supplied by 6 sq. ft. of ordinary grate-surface; and accordingly the fire is large but slack. The total heating-surface amounts to 882 sq. ft. The capacity is about 40 cub. ft., half of which is water-space and half steam-room. The whole boiler is firmly held together by cast-iron girders, and encased in non-conducting sides and top made of four thicknesses of light plate riveted together and kept about ¾ in. apart by ferrules, so as to form three closed air-chambers. This arrangement is specially adapted for marine boilers.

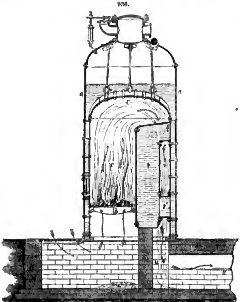
The flue from the boiler is made to pass through a box containing the three cylinders of the engine, passing first down the small or high-pressure cylinder, then up the middle one, and finally acting on the low-pressure cylinder. The temperature of the gases in this box varies from 400° to 500° Fahr. After leaving the box, they pass downwards through a vertical square flue 10 ft. long, giving up their remaining heat to the feed-water which is forced up through a wrought-iron coil of ¾-in. pipe contained in the flue, having 200 sq. ft. of heating-surface. At the bottom of this flue the gases enter a vertical iron funnel of 40 ft. height and 24 in. diameter. The heat is so completely abstracted by the feed-water coil, that after leaving it the gases have never been found hotter than 100° Fahr.

This small quantity of heat in the chimney gave sufficient draught to cause the evaporation of 8¼ cub. ft. of water an hour in the boiler; but by the aid of a small fan, driven by a belt from the main shaft of the engine, the evaporation was usually kept at 15 cub. ft. an hour. The evaporating power of the boiler was tested by means of a water-meter, and in an experiment of 5 hours' duration 390 lbs. of anthracite coal evaporated 420 galls. of water, which is about 10¾ lbs. of

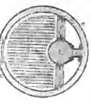
water the lb. of coal. There is no doubt that a larger boiler with small proportionate loss of heat by radiation to the outer air would give a still more favourable result.

Fig. 936 is an elevation, and Fig. 937 a plan, both in section, of Thomas Dunn's vertical boiler.

936.



937.



a is the shell, *b* the grate, *c* the fire-box; *t* is a large pipe which is kept full of water, the communication between the water-space surrounding the fire-box being effected by the branch pipes *t'*: to the outside of the tube *t*, and to the inside of the fire-box, are riveted T or angle irons, to hold in position the fire-clay or other slabs t^2, shown in Fig. 937; these slabs and the tube *t* form the partition to separate the up-draught from the down-draught; and the fire-clay of the slabs when red-hot igniten the smoke, and consumes it before it arrives at the flue *u* communicating with the chimney.

Dunn's vertical boiler with two fire-grates is shown in Figs. 938, 939. *a* is the shell, *b b* the grates, *c* the fire-box, divided in the centre by the two water-partitions W, W, the space between which forms the down-flue. The upper end of the partitions W, W, is partially closed by a perforated fire-clay top W', the object of which is to ignite the inflammable gases, and to prevent the passage of smoke into the down-draught flue. At the bottom of the down-flue are placed the pipes V, through which the feed-water passes, and is thus partially heated in passing to the boiler.

Figs. 940 to 944 illustrate a very novel and useful arrangement, introduced by Hawksley, Wild, and Co., of Sheffield. It consists in building a furnace for puddling, heating iron and steel or other material, inside the boiler-flue, thereby utilizing the waste heat.

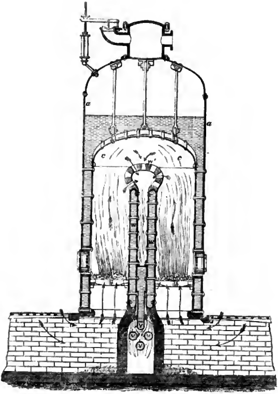
A is the steam-dome; B, furnace-door, the doors are placed on both sides of the furnace, so that it can be worked as a right or left hand furnace, or, in case of long forgings, right through; C, firing-hole door; D, fire-brick lining of furnace; E, furnace-bed; F, slag-bridge; G, tapping-hole for furnace-slag; H, heat-retainer for furnace-neck; I, circulating water-tubes; K, flange arrangement, for expansion, contraction, strengthening, reducing flue, and retaining the heat.

Robert Daglish and Co.'s multitubular boiler is shown in Figs. 945, 946, 947. A, A, is the stop-valve with safety-valve, B steam-dome, C mauwny and cover, D chimney and damper, E steam-gauge, F water-gauge and gauge-cocks, G feed-valve and pipes, ' mud-hole for clearing out.

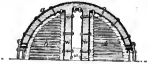
Samuel Smart and Co.'s vertical syphon water-tube boiler, shown in Figs. 948, 949, is of simple construction, consisting of a cylindrical shell with internal cylindrical fire-box, from the crown of which the water-tubes are suspended, hanging free into the fire. Every part of the boiler is easy of access for the purpose of cleaning; and as no strain is thrown upon any part by expansion or contraction, the tubes being fixed at one end only, the boiler is less liable than many other kinds to get out of order, and a great source of expense, in the shape of repairs, is thereby avoided.

Into each of the water-tubes a syphon is inserted, which extends down into the water-space of the boiler a short distance beyond the ends of the tubes. These syphons act as circulating tubes when the boiler is at work, supplying the water-tubes constantly with water from the water-

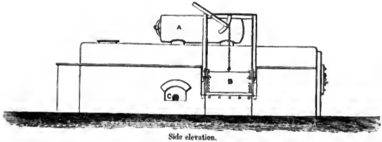
938.



939.

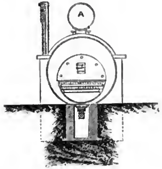


940.



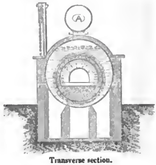
Side elevation.

941.



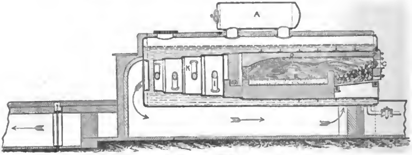
End elevation.

942.



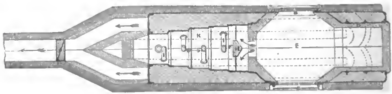
Transverse section.

943.



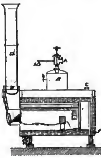
Longitudinal section.

944.



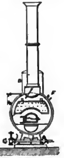
Plan.

945.



946.

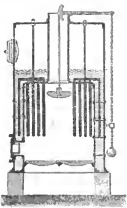
947.



casing, where it has a tendency to keep cooler than in the upper part of the boiler, but by means of the circulation through the syphons the temperature is equalized.

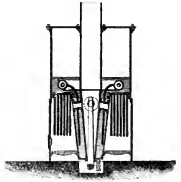
The tubes used under ordinary circumstances, in stationary and marine boilers, are of an external diameter of $1\frac{3}{4}$ in. and $2\frac{1}{4}$ in., with the exception of the portable boilers, in which smaller tubes are used.

948.



Stationary.

949.



Portable.

In the portable boiler, Fig. 949, the water-space surrounding the fire-box is omitted for the sake of lightness, and the hanging tubes are simply enclosed in a sheet-iron casing which carries the fire-grate. The central flue is carried down below the grate, and a water-space of the shape of an inverted cone is constructed around this flue, with short lateral flues for the escape of the smoke. Into this water-space the ends of the syphon tubes are taken, and the action will be precisely as in the stationary boiler already described. The blow-off cock is situated at the bottom of the conical water-space, and into the bottom opening of the flue the exhaust-pipe of the engine is fitted so as to close the opening, the nozzle of the exhaust-pipe terminating just above the lateral smoke-flues, and the exhaust steam is by this arrangement made to produce a powerful blast. In cases where even this central cone adds too much to the weight of the boiler it is dispensed with, and the circulation and blowing out is provided for by means of a peculiar arrangement of two-way cocks, and the boiler is made without any water-casing at all.

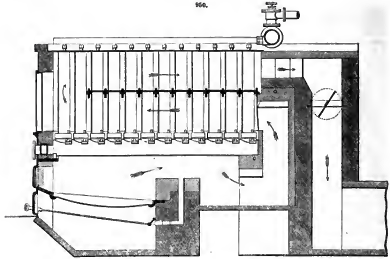
By using very small tubes in these boilers, a large amount of heating-surface can be put into a very small space; and as the boiler contains only a small quantity of water, which is made to circulate very rapidly over a large surface in very thin streams, steam is generated in a few minutes, and with a good blast in the chimney a quantity of steam is supplied for any length of time.

Howard's boiler, Figs. 950, 951, 952, 953, consists of a series of vertical tubes, 4 ft. 6 in. long and 7 in. in diameter, of wrought iron, welded, and closed at the upper end by flat plates less than half an inch thick welded in. Round the lower end of these tubes a heavy ring of cast iron with two projecting lugs is fixed. The tube is roughened at the lower end for a length of about 4 in., it is then placed in a mould and the metal cast about it. There results so perfect a union that the tube and the pipe are virtually rendered one. The tubes are disposed in transverse rows in a flue intervening between the furnace proper and the chimney. The lower ends of all the tubes in a transverse row are united by a cast-iron tube about 10 in. in diameter outside, and of considerable thickness. This tube is further strengthened by transverse perforated partitions. It will be seen that on the upper side of each cast-iron tube, flat pieces, or pedestals, are cast. In each of these is turned an annular groove as wide as the end of the vertical tube is thick, say $\frac{3}{8}$ in., and of considerable depth. The ends of the vertical tubes project slightly beyond their cast-iron base rings, and this projection fits into the circular channel before referred to. The end of the tube is turned off in the lathe.

In two opposite corners of the squares or pedestals on the cast-iron tube, recesses are made, and into each of these is slipped a heavy gun-metal tapped nut. These nuts can be drawn out or put in laterally, but they are held down by the cast iron of the pedestal which overhangs them on three sides. The base rings of the vertical tubes have lugs cast on them, which, when the tube is put in place, correspond with the gun-metal nuts to which they and the tube with them are secured by two bolts, one on each side, screwed into the nuts. Before the tube is put in place, a ring of composition, made of lead and tin, is dropped into the annular groove, and on this the end of the tube rests; and being forced down by the two bolts at opposite sides, makes a joint tight at any pressure which the tubes can sustain, and yet one which may be made and broken ten times in the day if necessary.

Each tube has within it an internal one, similar to that introduced by Ogle, rising up through the water-space, dividing the water into annular and central columns. The current of heated

950.



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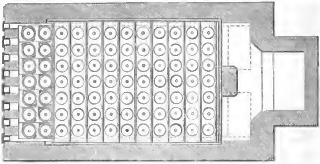

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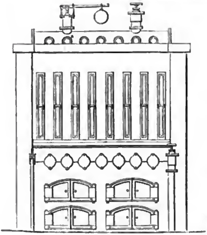

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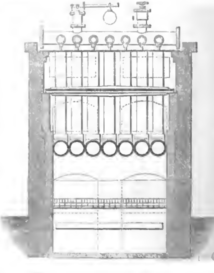


gases impinging upon the tubes, causes the water in the outer spaces to rise to the top and flow down to the bottom of the inner tubes; in consequence, a most active circulation is kept up in every part of the boiler.

From the upper ends of the tubes a short piece of welded gas-pipe rises. This pipe serves to carry off the steam to the main steam-pipe. Between every double row of generating tubes one steam-pipe is fixed horizontally, and the short tubes are bent over by an easy curve and screwed on to the sides of these secondary steam-pipes. All the secondary pipes open into one large pipe running at right angles to them. On this is fixed the safety-valve, and to a flange at one end the steam-pipe to the engine, or, where more boilers than one are used, a branch of that pipe is fixed. The effect of this arrangement is that the generating tubes are only secured at one end, and can, therefore, expand or contract as they like without imposing any strain on any part of the boiler. The steam-pipes are also free to move as they wish, the curve in the small pipes from the generating tube providing sufficient elasticity to meet any demands which are likely to be made on them. The cast-iron bottom mains can expand and contract as they please, and in any direction.

The manner in which the feed-water is introduced will be easily comprehended. Each transverse main has its own supply-pipe.

The furnace consists of the fire-chamber proper, which contains the grate, covered by a heavy brick-arch. In front of this is the tube-chamber, answering very much to the hearth of a puddling furnace; and under this last the flues are returned before going to the chimney. It is one of the distinguishing principles of this boiler, that no joint of any kind is exposed to the action of the fire, or heated products of combustion, while they retain a temperature much above that of the steam within the boiler. In order to carry out this object, the tiers of vertical tubes are set as follows:—The transverse cast-iron mains rest on side walls, and a central wall which establishes a wheel draught; the mains are fixed rather closely together, and, as soon as they are put in place, cast-iron plates are laid between them on flanges or ribs cast on the sides of the mains for the purpose; on these are laid bricks and fire-clay to such a height as to cover the junctions of the tubes with the mains effectually; the lower half of the mains project into the under-flues and absorb the last dregs of heat from the gases on their flight to the chimney. On the upper ends of the tubes wrought or cast-iron plates are also laid, and these are covered with six or eight inches of sand to keep in the heat. By taking off the sand and removing a couple of plates, access may always be had to the interior of the tube-chamber. It will be remarked that the whole tube, steam-space and all, being exposed to the heat, its upper portion would be liable to rapid destruction. To prevent this a provision apparently insignificant, but really very important, is introduced, in the shape of certain screens of fire-clay, which extend across the tube-chamber and protect the upper portions of the tubes from the impact of the flame.

954.

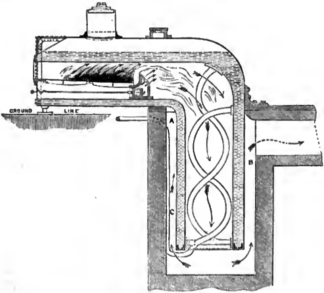
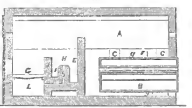


Fig. 954 is a longitudinal section of one of Thomas Dunn's boilers. The lower portion of this boiler is at right angles to the upper portion, and is contained in a chamber or pit of fire-brick: the products of combustion on leaving the flue surround the lower part of the boiler, A, B, C, and

escape to the chimney by the flue B. In this boiler the fire-brick bridge rests upon a hollow perforated cast-iron chamber, within which is a sliding wedge block; this block is now shown open to admit air behind the bridge, and it can be closed from the front of the boiler by the handle and rod shown in the figure. The pipes for heating the feed-water are placed in the flue; and as these pipes are connected to the upper and lower sides of the flue, there will be a constant circulation in the feed-water pipes.

Charles T. Boardman's arrangement for a boiler consists of two cylindrical boilers A A, Figs. 955, 956, placed side by side, and one inclined tubular boiler B, arranged below the near portions of the

955.

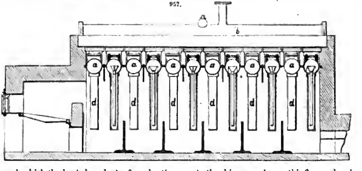


956.

cylindrical boilers, to which it is fastened by the water-legs C C. The object of this arrangement is to provide for the collecting and retaining of the sediment contained in the water in the coolest portion of the generating apparatus. An air-duct b and a mixing-chamber H for the admission of air from the ash-pit, L, to mix with the gases of combustion, are also peculiar to this boiler. D D are walls for setting; E, the pier; F, connected parallel upright walls; g, the return flue; G, the fire-place; I, J, the bridge-walls; d d, flues.

Fig. 957 is a longitudinal vertical section of the Field boiler. The furnace is constructed of brickwork in the ordinary manner, a large flue or chamber being formed at the back, into and

957.

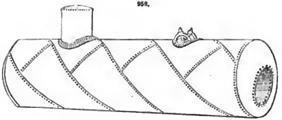


through which the heated products of combustion pass to the chimney. Across this flue or chamber are placed a number of inclined cast-iron tubes a, connected by flanged joints with bolts and nuts at their higher extremities to a longitudinal cast-iron tube b, constituting the main steam-space. A corresponding longitudinal cast-iron tube, similarly connected to the lower ends of the inclined tubes, and protected by brickwork from the direct action of the products of combustion, serves as an equivalent for the water-casing employed in the ordinary vertical Field boiler, and constitutes a receptacle for the collection and deposit of sediment. The under-sides of the inclined cast-iron tubes have bosses cast upon them, as shown, and tapering holes are bored, into which the wrought-iron *Field tubes*, d, are drifted in such manner that they hang down into the flue. On the upper part of the inclined pipes are formed a number of bosses, through which holes are drilled above each of the Field tubes, and rather larger in diameter than the latter, thus affording ready means of access not only to them but likewise to other parts of the interior of the boiler. Each hole is closed by a tapering plug, secured in its position by two bolts and nuts. The radiation of heat is prevented by iron plates resting on ledges above the inclined tubes, and covered with ashes. Cast-iron plates are placed across the upper and lower parts of the flue, for directing the course of the products of combustion, so that they may impinge in the most efficient manner upon the Field tubes, the circulation of the water in which is of a very perfect character.

Wright's diagonal seam boiler is shown in Fig. 958. It will be observed that in this boiler no three corners meet; this renders the boiler much stronger than the ordinary straight seam boiler.

Figs. 959, 961, show sections of Hawksley, Wild, and Co.'s single-flued, and Fig. 960 cross-section of their double-flued boiler. The flue is strengthened by flanging the smaller rings of plate; each flange in this flue is an expansion-joint, which allows the separate rings to expand and contract without increasing the steam upon the ends or shell of the boiler. A, Fig. 961, shows the combustion-chamber.

958.



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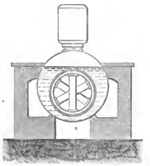

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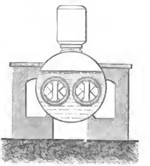
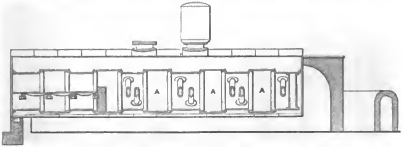


961.



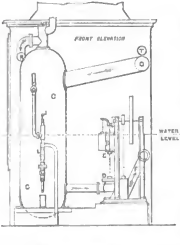
Martin Benson's high-pressure boiler is shown in Figs. 962 to 964. Fig. 962 is a front elevation, showing the receiver and circulating pump; Fig. 963 is a longitudinal section of the boiler; and Fig. 964 a transverse section at right angles to Fig. 963.

The boiler is composed entirely of tubes, A, Fig. 963, arranged in a series of horizontal rows over the fire. B B are doorways at the front and back of the boiler, for fixing, disconnecting, and taking out the tubes. C, Fig. 962, is the water and steam receiver; D the circulating pump, which draws its supply of water from the receiver C, and is worked by the small donkey-engine E above. F is the main supply-pipe from the circulating pump, to which the lowest tubes of each section of the boiler are connected. G is the main delivery-pipe, to which the top tubes of each section are joined, and into which the water and steam together are delivered from the tubes and thence discharged into the upper part of the receiver C.

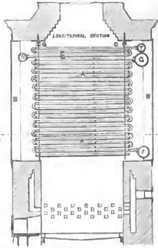
The steam generated in the tubes is driven up with the water through the tubes and discharged through the pipe G into the receiver C, where the steam and water are separated; and the water is then again taken by the circulating pump and returned into the tubes. In starting the boiler, the receiver is supplied with water until its level reaches the fifth or sixth row of tubes from the bottom, as shown by the dotted line; as the circulating pump is standing still at first, in consequence of having no steam to work it, the slide-valve is allowed to be lifted off its face by the pressure of the water, and lets the water flow past the pump direct through into the tubes. The fire is then lighted and steam raised from the water in the tubes, which starts the circulating pump to work.

Benson's boiler was first introduced in the United States, but the one we have described has for many years supplied steam for a 60-H.P. steam-engine at James Russell and Sons' works at Wednesbury.

962.



963.



964.

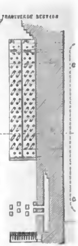
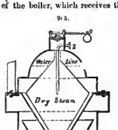


Fig. 965 shows one of Loader and Child's boilers. The principal feature of this boiler is the introduction of a reservoir or steam-chest in the centre or heart of the boiler, which receives the steam as it is generated, thereby providing dry, and, to a considerable extent, superheated steam; and at the same time the action of this boiler is to throw a thin body of water to the heating-surfaces, by which means steam is rapidly generated by a small quantity of concentrated heat.

965.



The boiler, Fig. 965, is the one which Loader and Child construct for small purposes. It has a cast-iron vertical case, with a copper cone or shell; the supply-tank is formed round the case and sides, and is heated by the flues on the reverse side. By this means much of the heat is utilized. The boiler shown in Fig. 965 is usually heated by gas when not more than 2-horse power is required, but this boiler is easily arranged so that ordinary fuel may be employed.

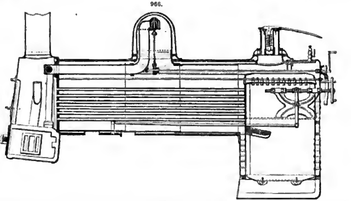
Locomotive Boilers.—We give, with some alterations, the following illustrations of locomotive boilers from Zerah Colburn's valuable work on 'Locomotive Engineering.'

In a locomotive boiler the outside and inside fire-boxes are made, the former of iron and the latter of copper. The water-space between them, and which completely surrounds the inner fire-box, is closed at the bottom by a square bar. This bar is bent and welded to the proper form, to extend around the bottom of the inside fire-box, and it is riveted and tightly caulked to both fire-boxes. The water in the water-spaces is in free communication with the rest of the water in the boiler; and thus the flat sides of the respective fire-boxes are exposed to the full pressure of the steam, which tends to burst the outside fire-box, and to collapse the inside fire-box. These flat sides, by themselves, would be unable to resist the strain upon them; but as the strain upon the respective fire-boxes is in opposite directions, and necessarily equal for equal areas of surface, tie-bolts, or, as they are called, stay-bolts, are screwed through the plates at frequent intervals, so as to connect the two fire-boxes securely together, the ends of the stay-bolts being also riveted, or spread out by hammering so as still further to increase their holding power.

The flat top of the inside fire-box is of course equally weak with the sides. It could not be satisfactorily secured by stay-bolts to the roof of the outside fire-box, and it is stiffened, therefore, by a series of iron bars, placed on edge, and of considerable depth, and which are firmly connected to the roof or crown of the inside fire-box by rivets. The roof, therefore, can only be crushed downwards by bending these bars, which are of great strength, at the same time. These bars usually extend in the direction of the length of the fire-box, as shown in Fig. 966; but they may extend across it, as shown in section on the roof of the inside fire-box in Fig. 967. These stay-bars bear on the fire-box only for a short distance at each end, iron rings or washers being

interposed between them and the roof-plate at the points where the bolts or rivets which secure the bars pass through. This permits the water to circulate under the bars, and prevents the roof-plate from being burnt, as it would be if the water were excluded from the whole under-surface of the stay-bars.

966.



A horizontal grate of thin and deep bars is fitted across the bottom, forming the bottom of the fire-box; and a door is made to open into the fire-box from the foot-plate. The opening for the door has to be made through the plates of both fire-boxes; and in order to keep the water-space tightly closed, a ring of iron, of which the inner diameter corresponds with that of the door, is riveted between the outside and inside plates.

Thin brass tubes, generally 2 in. in diameter, and from 10 ft. to 12 ft. long, are employed to conduct the hot gases from the fire-box to the chimney, the number of tubes varying, according to the size of the engine, from 100 to 200, or more. The arrangement of these tubes, the uppermost row of which is covered by from 6 in. to 8 in. of water, is shown in all our sections of locomotive boilers. The front plate of the inside fire-box and the front plate of the cylindrical portion of the boiler are accurately drilled, to receive the ends of the tubes, which pass through the plates, and are made steam-tight within them by means of ferrules of wrought or cast iron, which are driven into the ends of the tubes, so as to force them tightly into contact with the interior surfaces of the holes in the tube-plates. Such is the tightness with which the tube-ends are thus secured in their plates, that not only is there no leakage of water, as long as the joints are kept in good order, but the tubes serve as ties to prevent the respective tube-plates from being forced outwards, as they otherwise would be, by the pressure of the steam. Through that portion of the boiler above the tubes a number of tie-bolts extend longitudinally from the smoke-box tube-plate to the back-plate of the fire-box, to hold these plates together against the pressure of steam tending to force them apart.

The tubes lead into a closed chamber, formed upon the front end of the boiler, and called the smoke-box. Although the smoke-box has a removable door in front, this is tightly closed when the engine is ready for working, and then there is no inlet of air to the smoke-box except through the tubes, and no outlet except by the chimney.

Before steam is raised, and when the boiler is empty, it is first filled with water to the height of a few inches above the fire-box, by means of a hose connected with a cock placed on any convenient part of the boiler. In order to know when the water is at the right height there are two gauge-cocks fixed in the back-plate of the fire-box, towards the engineman's foot-plate, the one cock a few inches above, and the other as much below the proper level of the water within the boiler. These cocks have steam-tight fittings connecting them with a glass tube, within which the water, having free access from the boiler through the lower cock, is free to rise and fall, the surface of the water in the glass being under the pressure of the steam, freely admitted from the boiler through the upper cock. The water within the gauge-glass thus has the same level as that in the boiler; and the engineman has only to look at this glass to see what the height of the water is.

To prevent cinders and live coals from falling through the fire-grate upon the line, and partly for another reason, an *ash-pan* is fixed beneath the fire-box, and a few inches off the rails.

It is often important, when the engine is standing, to prevent any access of air to the fire-box; and hence the ash-pan is made to fit tightly to the fire-box on all but the front side. This side is opened or closed at pleasure by a hinged plate, called the damper, which is adjusted by a rod worked from the foot-plate. When the engine is running rapidly, with the damper open, a slight advantage is also gained by the rush of air into the ash-pan. At 60 miles an hour, or 88 feet a second, the pressure of the air against the moving surface would be over 1 oz. a square inch, or 9 lbs. a square foot. For countries where much snow falls, it is necessary to have a damper also at the hind end of the ash-pan, as otherwise it would soon become choked with snow when there was more than a few inches in depth of this upon the ground. In going forward, the front damper is then closed and the hind one opened.

The particulars we have just given are well illustrated by Fig. 966, which is a section of a boiler designed for a goods locomotive by John Ramsbottom. Fig. 966 also shows the steam-dome and steam-pipe.

Fig. 967 indicates the type of boiler used for passenger locomotives by the Rogers Locomotive and Machine Works, U.S.

967.

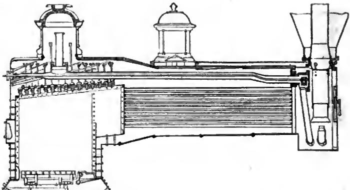
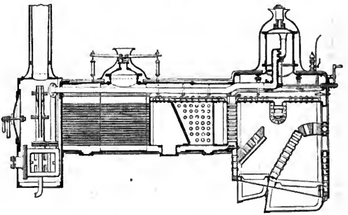


Fig. 968 represents the boiler designed by Joseph Beattie, and used on the London and South-Western Railway, for burning coal without smoke. The fire-box is divided by an inclined water-partition into two compartments, each having its own door, fire-grate, ash-pan, and damper. The principal fire is maintained in the box nearest the foot-plate. The gases rising from the coal are

968.



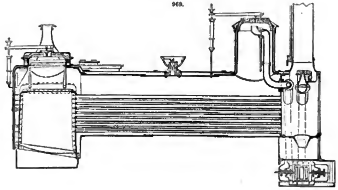
met by a number of fine streams of air entering through the perforated door, and both the gas and air rise through a grating of fire-clay tiles into the upper part of the second fire-box, on the grate of which coal is burnt only slowly, with a slight and carefully-regulated admission of air through the front damper.

The mingling air and gases are deflected downwards by a hanging water-bridge, over a fire-brick arch and through a series of fire-clay tubes into a combustion-chamber 4 ft. 6 in. long, from which more than 375 small boiler-tubes lead into the smoke-box.

The boiler shown in Fig. 969 was designed by John Haswell for the Austrian State Railways. It is used in steep-gradient locomotives for curves of 275 ft. radius.

Fig. 970 shows the form of boiler constructed by James Cross for passenger engines on the St. Helen's Railway.

969.



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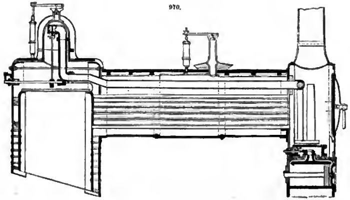


Fig. 971 represents the boiler for a passenger locomotive constructed by Robert Stephenson and Co. for the Stockton and Darlington Railway.

971.

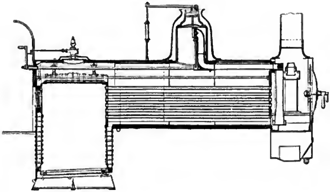


Fig. 972 is the type adopted on the South-Eastern Railway for coal-burning coupled passenger-engines.

972.

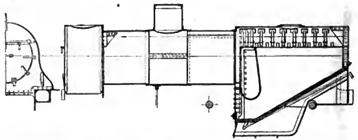
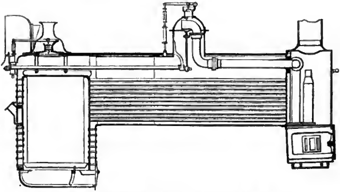


Fig. 973 exhibits a boiler for a goods engine used by John Wakefield on the Great Southern and Western Railway, Ireland.

973.



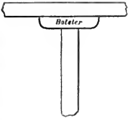
Of all the boilers we have enumerated, none is superior to the *Whittle* boiler.

See CONDENSERS. CORNISH ENGINES. DETAILS OF ENGINES. ENGINES, *varieties of*. EXPLOSIONS: *Boiler*. GEARING. INCRUSTATION *of Boilers*. JOINTS: *riveted*. LOCOMOTIVES. MARINE ENGINES. PARALLEL MOTIONS. PYROMETERS. SLIDE-VALVES. STATIONARY ENGINES. STEAM and the STEAM-ENGINE. VALVES.

Works relating to Boilers:—'Report of the Committee of the Franklin Institute on the Strength of Materials for Steam-Boilers,' Philadelphia, 1837. R. Armstrong, 'An Essay on the Boilers of Steam-Engines,' 8vo, 1839. T. Wicksteed, 'On the Cornish, Boulton and Watt Pumping-Engines, and Cylindrical and Waggon-head Boilers,' 4to, 1841. T. Craddock's 'Chemistry of the Steam-Engine,' 8vo, 1847. B. H. Bartol, 'A Treatise on the Marine Boilers of the United States,' Philadelphia,' 1851. Armstrong and Bourne, 'The Modern Practice of Boiler Engineering,' crown 8vo, 1856. A. Armengaud, 'Traité Théorique et Pratique des Moteurs à Vapeur,' 4 vols., 4to, Paris, 1861–2. B. F. Isherwood's 'Experimental Researches in Steam Engineering,' 2 vols., 4to, New York, 1863–65. F. A. Paget, 'On the Wear and Tear of Steam-Boilers,' 8vo, 1865. N. P. Burgh, 'Modern Marine Engineering,' 4to, 1867. V. Pendred, "On Water-Tube Boilers," 8vo, 'Trans. Soc. of Engineers,' 1867. Zerah Colburn's 'Locomotive Engineering,' imperial 4to, 1869. W. J. M. Rankine, 'Manual of the Steam-Engine, crown 8vo, 1869.

See also papers by Dunn, Colburn, Russell, Perkins and Williamson, Longridge, Goodfellow, Spencer, and others, in the 'Transactions of the Institute of Mechanical Engineers,' and papers by various authors, in the 'Trans. Inst. Naval Architects.'

974.



BOILER-PLATES. FR., *Tôle à chaudière, étole*; GER., *Kesselplatten*; ITAL., *Lamiera da caldaie*.

See BRIDGES. RIVETED JOINTS. STRENGTH OF MATERIALS OF CONSTRUCTION.

BOLSTERS. FR., *Estampes, perçoires*; GER., *Lochscheiben*; ITAL., *Cuscinetto*.

Bolster.—In carpentry, a short piece of wood, Fig. 974, interposed horizontally between the head of a post and a beam which it supports. It is also called a *corbel-piece*, as it shortens the bearing between the posts. The chief use, however, of a bolster is to prevent the head of the post crushing into the part of the beam which rests on it, when the latter is heavily loaded. Bolsters are generally used in timber bridges, masons' scaffolding, and so on.

The term bolster has also been applied to the pieces of timber placed across the ribs of the centering of an arch to support the voussoirs; but these are more generally known by the name of *laggings*, for which see CENTERING.

BOLTING MILL. FR., *Blutoir*; GER., *Beutelmühle*; ITAL., *Buratto, Frullone*; SPAN. *Cedazo*.

See BARN MACHINERY. FLOUR MILLS and FLOUR MACHINERY.

BOLTS. FR., *Boulons*; GER., *Bolzen*; ITAL., *Chiodi a perno*; SPAN., *Grillos*.

See NUTS and BOLTS.

BOND. FR., *Appareil, Assemblage*; GER., *Mauerverband*; ITAL., *Legamento dei mattoni*.

Bond is a mode of connecting two or more bodies by overlapping.

In *Brickwork* and *Masonry*, it is the mode by which a number of small pieces are combined to form a large mass so that no joint in a course shall occur over a corresponding joint in the next course, which is termed breaking joint.

Bricks are usually in length about twice their width, and in thickness about one-third of the length. For bonding, however, the latter dimension is not of much importance, provided it is uniform in all the bricks of a course.

When a brick is so placed in a wall that its greatest dimension is at right angles to the face, it is called a *header*, and when parallel to the face it is called a *stretcher*.

The methods of bonding brickwork generally adopted in England, are known as Old English Bond, Flemish Bond, and, to a limited extent, Garden-wall Bond.

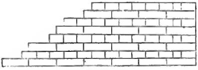
In Old English Bond, Fig. 975, a course of headers alternates with a course of stretchers.

In Flemish Bond, Fig. 976, headers and stretchers are placed alternately in *each* course.

In Garden-wall Bond, Fig. 977, one header is placed at the end of every three stretchers in each course.

Of the three methods of bonding, the Old English is the strongest, and takes less time to build than Flemish Bond; the joints are more uniformly broken than in the others, fewer *bats* or broken bricks are required to make the work solid, it contains more headers, and consequently there must be a better tie between the face and heart of the wall.

975.



Old English Bond.

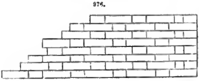
978.

1 Bk.

979.

$1\frac{1}{2}$ Bk.

976.



Flemish Bond.

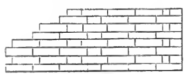
980.

2 Bks.

981.

$2\frac{1}{2}$ Bks.

977.



Garden-wall Bond.

982.

3 Bks.

Figs. 978, 979, 980, 981, and 982, show sections of walls in Old English Bond, from one to three bricks in thickness, with mode of bonding the heart of such walls.

Flemish Bond is considered to have a neater appearance; and in cases where a wall is faced with bricks of a superior quality, a less number is required than in Old English Bond.

Fig. 983 is a course of bricks laid in Old English, and Figs. 984 and 985 are courses laid in Flemish Bond; in the former the bricks all fit close together, and none of them require to be broken, or snapped, as it is termed, except the closer, the reason for which will be explained

presently. In the latter the headers must either be snapped, as in Fig. 985, or the heart of the wall filled up with small pieces of bricks, as in Fig. 984.

983.

984.

Garden-wall Bond is, as the term implies, chiefly used in the one-brick walls so frequently seen between the back-yards or gardens of town residences. The necessity of preserving a fair face on *both* sides of the wall is the cause of this bond being used, as, owing to the difficulty of procuring bricks all of one size, it is impossible to build a wall one brick thick in which both of the sides can be worked fair, in either English or Flemish Bond, particularly the former. This is shewn in Fig. 986, which is a course of headers laid in English Bond.

985.

986.

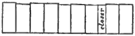


Fig. 987 shows how, by the use of Garden-wall Bond, this irregularity in the size of the bricks is rendered less apparent.

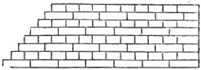
One-brick walls are frequently built in Flemish Bond, but one-half of the headers require to be snapped, which leaves no more cross-tie than Garden-wall Bond, while the longitudinal tie is not so good.

In half-brick walls stretchers only are used; this is called chimney bond.

In Belgium and north of Germany the system of bond used is that called Kruisverband, Figs. 988 and 989.

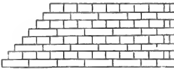
987.

988.



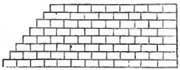
Kruisverband.

989.



Kruisverband.

990.

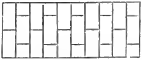


French Military Engineers' Bond.

The heading and stretching courses are as in Old English Bond, but the alternate stretching-courses *break* joint, while the joints of the corresponding heading-courses fall one over the other as in Old English Bond. As more of the joints are broken than in the other method described, this bond is considered to be the strongest of any. It does not, however, present so uniform an appearance as the Flemish or Old English.

The French Corps du Génie prefer to build the face of their walls with all headers, as in Fig. 990; but to obtain a tie between the face and heart of the wall, they place alternately in each course a half-brick, or *bat*, as shewn in Fig. 991.

991.



This mode they assert has the advantage of offering more resistance to disruption than any other. The longitudinal tie, however, is not so complete as in the English and Belgian systems, the joints being about one-tenth more numerous, and the waste occasioned by cutting the bricks is greatly to its disadvantage.

In the heart of a thick wall it is considered advantageous to lay occasionally a course of bricks

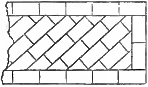
in a direction inclined to the face, as in Fig. 992. It is known by the name of Diagonal Bond, and when the direction of the brick is reversed in the next course this system adds strength to the wall; but it is attended with the disadvantage of having to cut the bricks to fit the back of those on the face.

From the fact that bricks are made in width equal to half their length, it becomes necessary, in order to break joint between the bricks of two adjoining courses, whether they be laid as headers or stretchers, to insert a quarter-brick in one of them at starting. This is called a king-closer, and is usually inserted in Old English Bond after the first brick is laid in the heading-course, and in Flemish Bond after the first headers. They are shown in Figs. 975 to 977.

In the French, and sometimes in the Belgian methods of bonding, the same result is obtained by starting one of the two adjoining courses with a stretcher cut to three-quarters of the usual length, called a queen-closer.

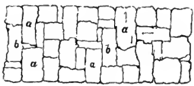
The bond adopted in *Ashlar* masonry is similar to the bond used in brickwork; closers, however, are seldom used in masonry, as the stones in the courses can be cut to any length required to make a perfect bond.

992.



Diagonal Bond.

993.



Plan.

In walls of rubble masonry from 1 ft. to about 3 ft. thick, it is usual to have at intervals of from 4 to 6 ft. a stone called a thorough, which runs from the back to the front, and so binds the wall together; but in thick walls, owing to the great length of the stone required, two stones of as great length as can be procured are made to lap in the middle of the wall; and in very thick walls, where stones cannot be found long enough to lap in this way, a third stone *b*, Fig. 993, called a tail or *heart bond*, is used to connect the two *bond-stones* or binders in the face of the wall.

Various special modes of bonding have been adopted in works of masonry where great strength is required, as in sea-walls and similar constructions. That used by Smeaton in building the Eddystone lighthouse consisted of a system of dovetailing and dowelling, for a detailed description of which the reader is referred to his account of this great work. See Construction. Masonry.

Bond-Course.—A course or horizontal layer of some material built at intervals into a wall in order to strengthen it.

When of brickwork, and built into rubble-stone or flint walls, it is termed a *lacing course*.

In brick walls built with ordinary mortar, two or three courses of bricks in *cement* are sometimes laid below the floor-line of the basement story of dwellings to prevent damp rising. In this case they would be called a damp course.

Formerly, courses of wood-bond, called chain-bond, were much used in building where there were usually one or more tiers to each story. The size was about 8½ in. wide by 5¼ in. high, or equal to the space occupied by a course of brickwork two bricks in height and two in width.

These bond-timbers went all round the walls and cross-walls, and through openings, from which they were afterwards cut out. They were connected at the angles, and no doubt tended much to strengthen the building for a time; but sooner or later decay set in, and the destruction of the building was the consequence. That and the increased danger from the effects of fire rendered chain-bond objectionable, which has in later years caused it to be almost abandoned.

Common bond of fir, 4½ in. wide by 2½ to 3 in. thick, is now more generally used, less as a bonding-course than a means of fixing battens or other finishings which are nailed against the wall.

When common bond is used solely for fixing battens, it is called *ranging-bond*, and is usually placed at intervals of from 18 in. to 3 ft., according to the strength of the battens.

Though common bond is open to the objections urged against chain-bond, but in a lesser degree, its use is preferable to plugging the walls where much of the latter is required, or even to the insertion of wood bricks, which are only short pieces of common bond about the size of an ordinary brick. The act of driving plugs shakes the wall, and destroys the adhesion between the bricks and mortar, and wood bricks shrink in time and drop out.

Ranging-bond should project a little beyond the face of the wall to permit a free circulation of air at the back of the battens or other work which has been fixed to it.

Common bond is usually described in specifications to be put all round each story in one or more tiers; all joints to be properly lapped at least 6 in., and the angles halved and notched or cogged. No bond-timber should be permitted in an underground story, as its decay would be more rapid and the danger to the brickwork resting upon it greater than in the upper stories.

When walls require strengthening by the use of bond-courses, *hoop-iron* is much to be preferred to wood. By its use Isambart Brunel, in 1835, managed to construct two half-arches of brickwork in lias-lime mortar, projecting 40 ft. from each side of a single pier, without any support at the other end.

Although only 4½ ft. wide on top, after another 20 ft. in length had been added to one end, a

counterpoise of 28½ tons was added to the other; yet it bore this enormous weight for upwards of three years, and probably would not then have given way if it had not been for a considerable settlement which had taken place in the foundations. Cracks appeared in the work, and, the wet getting in, it expanded during a severe frost, and so caused the failure of this wonderful piece of construction.

Several pieces of hoop-iron, 1½ in. wide and $\frac{1}{16}$th of an in. thick, were used; also pieces of fir, 1½ in. square, which did little more than assist in retaining the bricks until sufficient adhesion had taken place with the mortar to allow the hoop-iron to take effect.

Hoop-iron bond had also been used by Brunel in the large circular shafts, 50 ft. in diameter, leading to the Thames Tunnel, which were built above ground, and lowered into their places—a depth of 42 ft.—by excavating underneath, an operation successfully performed without a crack or flaw, which was considered to be due in a great measure to the use of the hoop-iron.

To prevent decay when in contact with the wet mortar of the walls, the hoop-iron should be well coated with a mixture of tar and pitch, and afterwards with sand. The form in which it was most generally used in building is that known as Tyerman's Patent Hoop-iron Bond, from 1¼ to 2¼ in. wide, and from No. 6 to No. 15 Birmingham wire-gauge in thickness. It is prepared from the ordinary hoop-iron by notching it at intervals of 12 in. on both sides alternately, Fig. 994, and turning in succession, in contrary directions, a triangular piece, so as to form claws, which catch in the brickwork and effectually prevent its being drawn out by any force short of tearing the iron asunder. In modern practice, however, the notching has been considered unnecessary.

994.

Tiers of two or more strips, according to the thickness of the wall, laid at every 3 ft. in height, have been considered sufficient in most cases. The mode of laying each tier is to place a strip on every half-brick in the thickness of the wall, continued over the whole length of the work, regardless of openings, as in wood-bond. Afterwards the parts across the openings are cut so as to leave a short piece protruding, which should be turned down against the face of the *jamb*. At all junctions it should be lapped, and the pieces carefully hooked to each other.

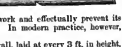
In footings or in thick walls exposed to great strains, strips of hoop-iron should be laid diagonally, interlacing with those laid in a longitudinal direction.

Bonding-courses of dressed stone have been used with advantage; they should be cramped together at each joint.

The ancient Romans used a large flat tile, about 2 ft. long by 18 in. wide, laid at intervals of about 4 ft. in height. Bonding-courses of this description, however, are more applicable to rubble masonry than to block-stone or brickwork.

Bonding-bricks are bricks of greater length than those of which the wall is built. They are used in hollow walls to tie the two faces together. Their length should be as much longer than the ordinary brick as the space over which they bond.

995.



Some very effective bonding-bricks have been introduced by a London manufacturer, the ends of which are of a dovetail shape, Fig. 995; and, where the precaution is taken to cut the adjoining bricks to fit, nothing can be more effective.

These bricks are usually made non-absorbent, by being glazed, so that damp cannot be conveyed by them from the outer to the inner skin of the wall.

When ordinary bricks are used in this way for bonding, they should be dipped in boiling pitch, or tar, to prevent the damp passing from wall to wall.

BOND-COURSE. Fr., *Chaîne*; Ger., *Band*; Ital., *Catena*.

See Bond.

BOND-TIMBER. Fr., *Pièce d'assemblage*; Ger., *Binde Hölzer*; Ital., *Catena*.

See Bond-Course. Fir in Bond.

BONE-MILL. Fr., *Moulin à os*; Ger., *Knochenmühle*; Ital., *Frantoio delle ossa*.

The mill invented by E. P. Baugh for grinding bones, ores, and other hard substances, is shown in Figs. 996 to 1001. Baugh's improvements refer to that class of cast-iron grinding mills, the cutting and triturating surfaces of which are made in the form of a frustum of a cone. The shell and burr are constructed of a number of cast-iron grinding sections, fitted and held together in a peculiar manner (which will be described presently), so that the sections can be readily removed to make way for others; the dress of the mill being thus rendered changeable to suit the substances to be ground; while the mill itself is more economical, both as regards its original construction and its lasting properties, and the variety of substances which it may be arranged to grind, than mills of the ordinary construction. The grinding sections of the shell are backed by an exterior casing, between which and the base, to which the casing is secured, are confined the sections, so that the latter can be readily disconnected from the mill. The several sections of the burr are secured to a block between a lip or ring, or other projection, at or near the lower edge of the latter, and a ring fitted to the vertical shaft, which carries the burr so that the sections can be readily detached. The ring, which aids in securing the grinding sections of the burr, has grinding teeth formed thereon, and a breaker or stirrer is fitted to and turns with the vertical shaft of the mill; provision being made for rendering it easily detachable therefrom, so that different forms of breakers may be applied to the mill. Certain detachable sections are used, acting in conjunction with the breaker for preliminary grinding; these sections being fitted to and backed by a casing, and held in position by a cap-plate secured to the same, and carrying the bearing for the vertical shaft which carries the burr. The vertical shaft, with its burr and other appendages, are supported on

a sliding step controlled by a lever and an adjustable weight, which tends to elevate the burr, but is limited in this tendency by a screw or other adjustable stop, the burr by this arrangement being maintained in the desired proximity to the shell, but being prevented from coming in contact therewith and injuring the grinding surfaces; the burr, at the same time, being at liberty to yield, should a piece of iron or other refractory material find its way between the grinding surfaces. In order to reduce friction and facilitate lubrication, a double cone of steel is interposed between the bottom of the vertical shaft and the bottom of the step in which the shaft turns.

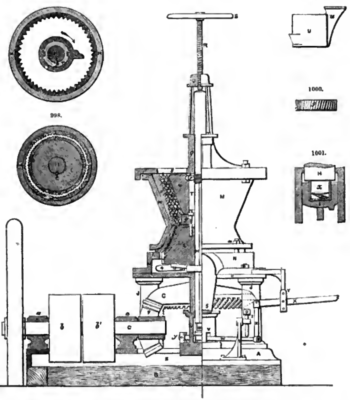
Fig. 996 is a half section and elevation of the improved mill; Fig. 997 is a sectional plan of the upper portion of the mill; Fig. 998 is a similar view of the lower portion; and Figs. 999 to 1001 are details, which will be referred to hereafter. A is the base-plate of the mill, secured to a foundation B, and on this plate are fitted suitable bearings *a a* for the horizontal shaft *c*, the latter being furnished at one end with a fly-wheel, and between the bearings *a a* are fast and loose pulleys *b b′*. At the opposite end there is a bevelled pinion F, gearing into a bevel-wheel G, which is so secured to a vertical shaft H, that both must turn together, while the shaft is at liberty to slide up and down through the boss of the wheel. This shaft has its lower bearing in a step I, shown on a larger scale at Fig. 1001 in a casing V, and which is secured to the base-plate A, as are also four columns J J, which support the lower plate K of the mill and its superstructure.

997. 996. 999.

1000.

998.

1001.



To the vertical shaft H is secured the burr of the mill, which consists of the block L, of cast iron, and the detachable cast-iron grinding sections *e*, the block being of the form, or approximating to the form, of the frustum of a cone, the sections conforming in shape to that of the block, and being secured thereto in the following manner:—Round the lower edge of the block there is a ring *f*, and against the inside of the upper projecting portion of this ring bear the lower ends of the detachable cast-iron sections *e*, the latter having at their upper ends lips or flanges bearing on the top of the block, and confined thereto by set screws or bolts *h*. The form of each section is such, that one section will fit accurately against the adjacent section, the whole of the sections thus forming a continuous grinding surface.

The shell of the mill also consists of a number of cast-iron grinding sections i, fitted together edge to edge, and backed by an outer casing M, of the form, or approximating to the form, of a frustum of a cone, to which casing the sections are fitted, and by which they are held in place, the lower ends of the sections being confined between the flange j of the casing M, and the flange k of the cast-iron ring N, by bolts m, which secure together the casing and the ring, the latter being confined to the plate K by bolts n. In the present instance the case M is carried upwards in the form of an inverted frustum of a cone, and is lined with detachable cast-iron sections p, which are held in place by the cap-plate P, secured to the top of the casing M′, this plate having openings $s\,s$, and a central boss q, through which the shaft H passes, and in which it turns.

A stationary nut Q, connected to the boss of the cap-plate P, receives a screw R, the upper end of which is provided with a hand-wheel S. It will be seen that the shaft H has a feather t, adapted to a groove in the block L of the burr, and to a similar groove in the ring g of Fig. 1000, above which a sleeve T is fitted to and turns with the shaft, as it has a groove to receive the feather. To the sleeve is fitted what may be termed the breaker, Fig. 999, which consists of a boss U, having one or more projections u, the sleeve having grooves adapted to keys or feathers in the boss of the breaker, Fig. 997. Both the breaker U and the sleeve T, as well as the ring g and the burr, are confined by a nut v adapted to screw threads on the vertical shaft H.

The foot-step bearing I, previously alluded to, consists of a cast-iron box, arranged to slide in the cylindrical casing V secured to the base-plate A, and is furnished with a steel bush w, in which turns the lower end x of the vertical shaft H. Between the bottom of the shaft and the bottom of the bush intervenes a double cone x', of hardened steel, made somewhat less in diameter than the shaft, as shown clearly in Fig. 1001.

A lever W, passing through a slot in the casing V, is hinged at one end to a pin on a stud y, secured to the casing, and bears against the under-side of the step I, the lever being connected at its opposite end by a link X to a lever X′, which is arranged for receiving a movable weight, and is hinged to a bracket Y, secured to the plate K; a set screw, 2, adapted to a nut on a stand, 3, secured to the base-plate A, serving to limit the upward movement of the lever X′.

Prior to setting the mill in motion, the lever X′ is so weighted as to more than balance the vertical shaft H with its burr and breaker, so that the said shaft may have an upward tendency, which, however, is limited by the set screw, 2, the latter determining the distance apart of the grinding surfaces of the shell and burr. By this arrangement the grinding surfaces are maintained in sufficient proximity to each other to act properly on the material to be ground, but will not come in contact with each other; at the same time, should a piece of iron or steel find its way between the grinding surfaces, the burr and shaft will yield and prevent injury to the mill.

The shaft H and its burr and breaker having been caused to revolve in the direction of the arrow, the bones, quartz, or other material to be ground, are passed through the openings $s\,s$ in the cap-plate P, to the conical space bounded by the detachable sections p. Here, by the combined action of the teeth or dress on these sections, and the revolving breaker U, the material is fractured and reduced to comparatively small fragments when it has reached the ring g; by the combined action of the teeth on the periphery of which ring, and those near the lower portions of the sections p, the material is reduced to a condition which permits it to enter the space between the grinding sections e of the burr and those of the shell. As this space becomes gradually narrower towards the lower end of the shell and burr, the material becomes gradually reduced, and finally leaves the grinding surfaces in the desired pulverized condition, and falls into the space within the ring N on to the slightly concave surface of the plate K, where it is acted on by the revolving sweep, 4, the latter causing the discharge of the ground material through a spout, 5, into any suitable receptacle.

By making the grinding surfaces in sections, not only can both shell and burr be made truly round, but the teeth can be made of the most irregular character; for instance, the teeth or dress can be formed by grooves crossing each other, or some of the grooves may be straight, some curved, others diagonal, according to the nature of the material to be operated on. An indefinite number of changes may be made in the character of the dress when this mode of constructing the grinding surfaces of conical mills is employed, an important advantage, as the *dress* must be made to suit different materials, and in many cases different qualities of the same material to be ground; a dress for grinding bones, for instance, would be unsuitable in some respects for grinding quartz; and in operating on other substances it may be advisable for the dress of one section to differ from that of another in the same mill. It will thus be seen that the character of the mill may be entirely changed by a simple and speedy change of sections, and that when the teeth of one or more sections have become worn, broken, or otherwise inoperative, their removal, and the introduction of new sections, renews the mill, whereas an ordinary cast-iron mill would, under similar circumstances, have to be discarded.

In removing the grinding sections, the screw R plays an important part; for should it be desired to remove the sections i of the shell and the sections e of the burr, all that is necessary is to first detach the nuts of the bolts m, loosen the nuts of the bolts n, and the nut v, and then operate the wheel S, so as to cause the end of the screw R to bear on the top of the vertical shaft H, and continue to turn the screw until the entire shell of the mill is elevated so far as to permit the withdrawal of the sections of the burr and shell and the introduction of others, after which the shell is lowered by turning the screw in a contrary direction, the nuts of the bolts m replaced, and the nuts of the bolts n, as well as the nuts v, tightened.

Should it be necessary to remove the sections p only, the nuts are detached from the bolts which confine the cap-plate P, and the latter is elevated above the mill by operating the screw R when the sections are at liberty. After elevating the cap-plate clear of the shaft, the nut v, breaker u, and ring q, may be readily removed.

It has been found, after repeated experiments, that the double cone x' performs most efficiently the duty of distributing to the lower bearing the oil contained in the space between the bottom of

the shaft and the bottom of the step I, at the same time preventing undue friction at the point subjected to the greatest shocks and strains. This mode of interposing the double cone between the bottom of the shaft and the bottom of the step may be applied to the lower bearings of all vertical shafts, to the pivots of swing-bridges and turn-tables, and other objects having a vertical bearing to which great strains are subjected.

For grinding some materials it is not essential that there should be a superstructure M′, and detachable sections *p*, or a breaker above the shell M, a simple hopper being in many cases all that is necessary to receive the material and direct it to the grinding surfaces; the latter, too, may (for grinding some materials) be straight instead of curved. It is preferable in most cases, however, to form teeth on the periphery of the ring *g*, as shown at Fig. 1000, so that it may serve the twofold purpose of aiding in the preliminary or first grinding, and of keeping the sections *e* of the burr in place. The lips of these sections *e* may, moreover, be dispensed with, the ring *g* bearing directly on the upper edges of these sections. The casing M, too, may be made in sections, or the grinding sections may be backed or held together by a suitable system of metal bands. See Agricultural Implements, p. 12, Fig. 27.

BOOT-MAKING MACHINERY. Fr., *Machines à faire les bottes*; Ger., *Maschine zur Anfertigung der Stiefel.*

The introduction of the sewing machine greatly facilitated the operations of boot and shoe manufacturers, and other workers of leather. The principal leather-sewing machines will be found in our article on *Sewing Machines*. But other boot and shoe making machines and tools are also employed to economize labour in this important branch of industry, the most useful and important of which are introduced under the present head.

1002.

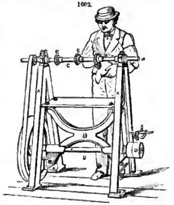
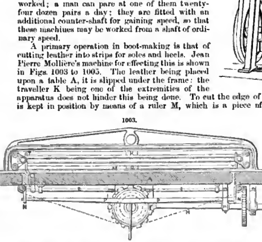


Fig. 1002 represents Gimson's machine for paring the edges of heels and soles of boots and shoes. This machine consists of two standards A with a stretcher B, a driving-shaft D which gives motion to a spindle *c* driven with high velocity; on this spindle, discs or circular cutters E are fixed; the boot or shoe is held against the cutter, the uppers being protected by a loose guard which runs in between the upper and the sole. These machines are easily worked; a man can pare at one of them twenty-four dozen pairs a day; they are fitted with an additional counter-shaft for gaining speed, so that these machines may be worked from a shaft of ordinary speed.

A primary operation in boot-making is that of cutting leather into strips for soles and heels. Jean Pierre Mollière's machine for effecting this is shown in Figs. 1003 to 1005. The leather being placed upon a table A, it is slipped under the frame: the traveller K being one of the extremities of the apparatus does not hinder this being done. To cut the edge of the leather straight, the leather is kept in position by means of a ruler M, which is a piece of iron with a longitudinal groove

1003.



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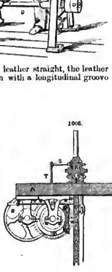

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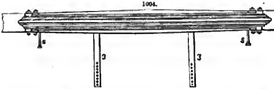
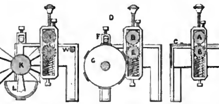


in it, in which the curved knife-blade or chisel O works when the ruler is down; and at each end of the groove is provided an opening into which the traveller K can pass. The ruler is

governed by two spring-rods N buried in the thickness of the table, and whose springs always tend to keep it raised: these rods are connected under the table by a yoke P attached to a treadle not shown in the figures.

When the leather is pushed under the rule, the treadle is depressed, thus pressing down the rule and keeping the leather firmly in its place. The handle R is then moved, throwing the parts for moving the chain into gear, and thus setting K in motion and cutting the leather. Arrived at the end, the traveller encounters one of the fingers S attached by levers T to a rod Q, forces it forward, and throws the chain out of gear, thereby arresting the traveller. The traveller is then let up, which will allow the springs N to throw up the ruler M, so as to let the leather pass, which is then cut straight. The workman pulls the leather towards him until its smooth edge comes up to the two pins S, and then the operation just described is repeated.

1006. 1007. 1008.



In preparing leather for uppers upon C. Rice and S. H. Whorf's plan, Figs. 1006 to 1008, the skin is first introduced between the feed-rollers A, B, of the splitting mechanism, and by them is forced against the knife C; the upper portion of the skin split by the knife C passes towards and between the draught-rollers D, E, which move it forward between the roller F and a rasper G, which latter roughens the under-surface of it. From the rasper the leather moves over a guide-bar W, between the pressure-roller I and the perforating-roller H; and finally it passes between the roller, and a brush K, which latter revolves through a vessel L containing cement, and applies the cement to the roughened surface.

A machine for cutting out boot and shoe soles, invented by J. W. Hatch and Henry Churchill, is illustrated by Figs. 1009, 1010. A is a shaft carrying at its lower end a shoe B, to which a punch C is secured; shaft A is provided with journals which fit in boxes secured to the front of a slide P, which, fitting in vertical guides in the framing of the machine, receives a vertical reciprocating motion from eccentric pin *p*, Fig. 1010, on the end of a driving-shaft Q.

When shaft A reaches its highest position, a spur-wheel E comes to gear with a toothed segment F′ on the front of a lever F; lever F has its fulcrum in a vertical pin *a*, and, at the time the shaft A is at its highest position, a cam I strikes the rear end of the lever F and moves it round its fulcrum *a* a sufficient distance to cause a spur-wheel E with its shaft A to describe half a revolution.

When the shaft A is about reaching its highest position, the square part of it, *b*, rises above the guide J, and the round part of the shaft *d* comes in contact with the guide, thus permitting the shaft to describe its half revolution.

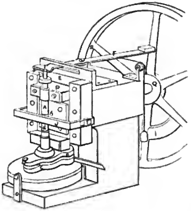
The boot-form introduced by Chilcott and Snell, Figs. 1011 to 1013, has a clamp E, which consists of a strip of sufficient length to reach from the nick at *f* to the top of the front-piece A. This clamp E is prevented from being pulled out laterally by entering a recess *g* in the nick, and is secured at top by a latch *h* catching a pin *i* on the top of clamp E. The inside of the strip is furrowed from end to end, and the recess in which it is received is correspondingly furrowed to hold the material securely. The clamps I, I, fitting to the outside of the front-piece and partly over the clamp E, are attached to screws K K, which fit in female screws in the rod L. This rod L is fastened at its lower end to the bottom part of the front-piece. Its upper end is attached to the front-piece by a plate P in the manner shown in the figures. The plate P is fastened to the front-piece by a screw N, which can be taken out; pins *j j* serve to hold the clamps I, I, in position.

Figs. 1014, 1015, refer to J. and E. Arthur's machine for cutting uppers and soles from sheets of india-rubber. The endless apron B, which has an intermittent motion, receives the sheet of india-rubber *a*; the cloth J between the rubber and apron being properly wetted by its passage through a water-trough F. Two endless chains K carry the die-frames *d* with the heated dies *f*. The die-frames are pivoted to the chains at *g*, and are carried by the chains through the stove M and over the roller D. When over the roller D, the sides of the die-frames come under stationary plates *h*, and are in their onward motion firmly pressed upon the india-rubber, which is thereby drawn over the roller D at the same speed with the dies. The dies cut, or rather melt, through the rubber taking out pieces according to the shape of the dies. The pieces are conducted to the apron G by means of thin fingers (twenty) secured to a swinging frame *r*, whilst the waste still remaining attached to the piece *a* passes over rollers *l* and *m*, and between *m* and *n*, on to the apron *o*. As soon as the die-frame, after having performed the cutting, comes round the chain-roller *b*, the extensions *v* of the frame will strike and pass under the pin *w*, which throws up the front part of the die-frame so as to make room for the die-frame which passes below.

In Mollière's machine for cutting uppers, Fig. 1016, G is the piston of the steam-cylinder operating the bed I. The skins are laid upon the bed I, and the cutters, consisting of pieces of bent steel, placed upon the skins, and then steam-power applied to lift and press the table, skins, and cutters, against the head-block C, so as to cut pieces corresponding to the shape of the cutters.

With Mollière's machine for rasping and dressing heels and soles, Fig. 1017, the operator applies the bottom of the sole first to the tool T, for the purpose of having the rough parts of the leather and the jags of the nails taken off; the sole is then applied to the tool *f*, and the heel to a tool *r*, to finish the dressing. During the whole of the operation the tools are kept turning very rapidly.

1009.



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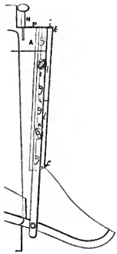

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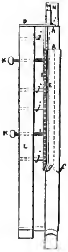
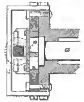
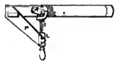


1010.



1013.



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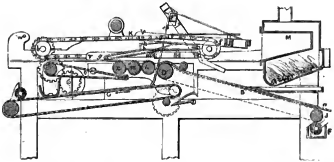

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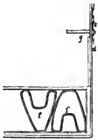

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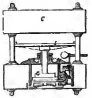

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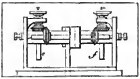
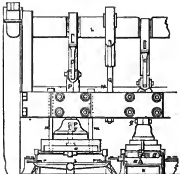


Figs. 1018 to 1023 refer to Mollière's machine for cutting out, punching, and stamping soles. The cutting out, pricking, and stamping, or numbering of the size of the shoe, is done at one blow, by means of punchers a, of the shape of the sole and heel, provided with prickers d, and stamps e and P. m m and o are the detaching-rods, the rods m working through holes h in the punching-frames; the punches are operated by eccentrics upon shaft L, which eccentrics are so set that the punches will, one after the other, arrive at their lowest or punching position, so as to distribute more equally power and resistance. When the punchers pass upward, the pieces of leather encounter the rods m, which are stationary, and are detached by them from the punches. The rod Q serves as stamp, and also as detaching-rod for the heel-pieces. The workman holds the strip, and puts it under the puncher; but, as this must be done with great rapidity, the leather finds itself guided and stopped in such a way that it can be instantly moved into its place. The guides to effect this consist of two pieces r, forming the sides of a square—one of which is graduated, and has on it the numbers of the sizes. As the puncher is always in the centre, these guides must be governed by a single movement in their approach to and retreat from it. This is done by the following mechanism:—Two pieces S slide on a guide-bed, and have an oblique groove, in which plays a pin fixed to the guides r; these two pieces S are connected by the cross-tie t, and controlled by the screw u, which, being attached to a bracket, causes the traverse t of the pieces S to move forward or backward, so that the pieces S, by their oblique grooves, push forward the guides. The stopping-piece x is supported upon a small axis v; it is kept down upon the leather on the flat by the counter-weight y attached to the axis, while the puncher is cutting; a spring-catch hitches under the piece z, and lifts up the stopper as fast as the puncher rises, which leaves time enough to remove the leather that has been cut; when it gets up as far as it can, the piece z, which has described the arc of a circle, lets the catch go; and, being drawn down by the counter-weight y, the stopper falls back to its place.

1018.

1019.

1022.



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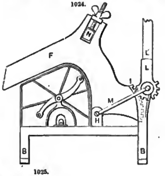
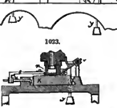


1023.



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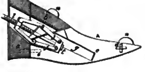

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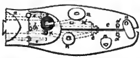
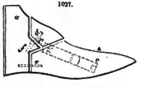


1027.

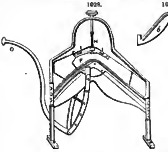


Horace Wing's wrinkling or crimping machine, Fig. 1024, consists of a frame B, upon which is arranged a crimping-plate F, so constructed as to leave its front end unobstructed. It is pivoted at the inner end to a fulcrum-bolt H, and operated by means of a gear-segment L, attached to a lever L', engaging with a corresponding gear-segment I on the outer end of the lower limb M.

Figs. 1025 to 1027 represent Warren Holden's boot and shoe stretcher. If one side of the boot is to be stretched, a knob n is attached to one of the parts c, and the corresponding side of the boot is properly moistened. The last is then placed within the boot, and the screw l is turned, thus forcing apart the sections of the last, and stretching the moistened side of the boot. If the

toe of the boot requires stretching, the link d is disconnected by removing the screw d'. The turning of the screw l, in the position shown by Figs. 1026, 1027, will expand the front ends of the parts. Should the instep require stretching, the levers $j\ j$ are placed in the groove i, Fig. 1025, and the levers then expand vertically. When in the groove g, the levers are placed horizontally.

1028.

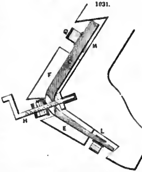


1029.

1030.

Figs. 1028 to 1030 illustrate H. B. Horton's crimping machine. A piece of wet leather having been laid across the jaws, it is, by the raising of them through the lever D, forced upon the crimp-form F; by the repeated sliding up and down of the jaws on the leather, it is thus smoothed, and embraces the crimp-form. Should there be any thin place in the leather, and the wrinkle not perfectly removed, the nearest set screw d is turned, and the wire $b\ b$ made to project beyond the face of the jaw opposite the screw. The angle-iron G, clamps I, and screw-rod H, serve to draw tight the leather on the crimp-form.

1031.



1032.

1033.

Referring to Figs. 1031 to 1033, which show Daugherty's boot-crimp, the slides L M fit loosely to the arms of the elbow G. The nut I is provided with projections $a\ a$, which extend up each side of the elbow so as to form two inclined planes which correspond with the inside of the clasp K, which clasp is perforated so as to traverse freely upon the screw H, and the inside of the arms are scored so as to gripe the leather upon the projections $a\ a$ of the nut. The edges of the leather having been inserted between the slides L M and clasps P Q, and between clasp K and nut I, the screw H is turned, by which means the elbow G is moved outward, and with it the clasps, thereby stretching the leather. As the screw is turned, it slips a little on the nut, and slides and draws the clasps on, so that the scored part of the clasps gripes the leather tight. The elbow, and so on, are received in a groove in the crimp-board A, formed by projections E and F.

Thompson's machine for polishing the soles of boots or shoes, Figs. 1034, 1035, is of simple construction, having a polisher or polishers $g\ h$, made of bone or other proper material, attached to a shaft f, which has a reciprocating motion imparted to it in any desirable manner.

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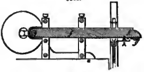


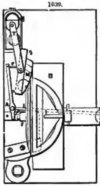
1037.

1038.

Figs. 1036 to 1038 represent A. Swingle's hand pegging-machine. By striking with a hammer upon the top of an awl-driver C, the spring-slider D is driven up into a handle A, splitting a peg from the block which is arranged in the space L between the said slider and the peg-wood driver M; to the latter is imparted a constant tendency to press the block forward by means of an elastic band N. The awl E and peg-driver F work through holes I and K in the slider, the principal object of the slider being to draw or force the awl out of the leather sole, or other articles, immediately after having been driven into the same. G is an india-rubber spring attached to the lower end of the awl-driver.

Hill's machine for skiving boot and shoe counters is represented, Figs. 1039 to 1041. A lever A', turning horizontally, has its fulcrum upon the upper end of a lever B'. Studs *e f*, projecting from lever A', rest respectively against the middle of the rocker-frame S and the end of shaft F. B' turns upon a fulcrum at *g*, and is operated by a foot-treadle below. By means of the levers A' B', the clamp-plate E and the rocker-frame S are simultaneously moved towards the rotary bed B; the clamp-plate being carried into contact with the leather to be skived, while the knife is borne against the thin edge of the clamp-plate and against the edge of the rotary cylinder, so that, whatever may be the thickness of the piece of leather, the knife will be made to adapt itself to that thickness. At the same time that the face-clamp is moved towards the cylinder-bed, the peripheral clamp will also be borne down upon a counter placed on the periphery of the cylinder and between the same and the clamp.

1039.



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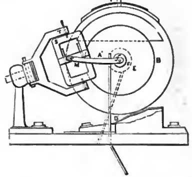

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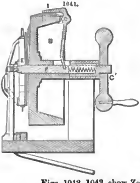

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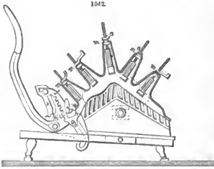

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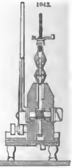

Figs. 1042, 1043, show Zeigler's boot-crimping machines. The jaws are corrugated, so as to work the leather away from the angle of the crimping-iron and into the foot and leg of the boot. The nuts *m* serve to stretch the leather upon the crimping-iron. The slots in the plate K are so constructed as, in combination with the segment-gear M and rack J, to move the foot of the crimping-iron into or between the jaws twice as fast as they move the leg, and to give the foot a compound motion which, in combination with the corrugations in the jaws, works the leather in the required direction to crimp it properly.

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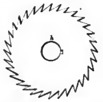
1046.

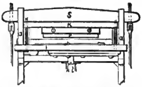


1047.

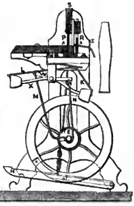
J. P. Mollière's machine for cutting the edges of boot and shoe soles is referred to in Figs. 1044 to 1047. This plan consists in arranging two revolving tools G and *h*, both of the same construction, only *h* being of larger size than G. The side of the shoe is first held against tool G, placing the edge of the guard-plate *a* between the upper and the sole. The shoe being thus slipped along to the point, and the same way with the other side of the shoe, the edge of the sole is finished with the exception of the heel. The heel is cut by the larger tool *h*, it being provided with a similar guard-plate K, in the same manner as the sole.

In working Griffin's machine for cutting out soles, Figs. 1048 to 1051, the operator places his foot on treadle H and moves it up and down, so as to impart to the shaft c a reciprocating rotary

1048.



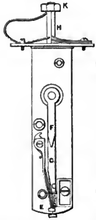
1049. 1050. 1051.



motion, he at the same time holding a strip of leather on the top surface of the table, and against a guide-bar z. After each cut, he moves the strip forward against the guide or stop bar. The carriage I has an intermittent reciprocating motion imparted to it, which carries each of the knife-bars K K in succession directly underneath the depressor-bar S, which, descending thereupon, forces the knife-bar and its knife P or R downward towards the cutter-block, and cuts through the leather. Fig. 1051 represents the soles as cut out by the machine. Each knife is elevated from the leather by the springs a on the rods that guide its bar K.

In R. H. Thompson's hand machines for pegging, Figs. 1052 to 1055, motion is given to a slide H by striking upon head K. The slide H carries the awl and peg-driver. The peg-driver is intended to drive one peg at the same time that the awl makes the hole for the next peg, the machine being moved the distance from one to the next by a slight pressure of the hand

1052.



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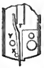

in that direction, this distance being measured, and this motion of the machine restricted to correspond, by the spring-spacer T. The point at the lower end of T, being held down by spring W, pierces the leather sufficiently to keep the machine from being easily moved out of place if a slight downward pressure is exerted upon the machine. Just as the slider H completes its descent, the arm O on the slider operates the tumbler P, the latter taking into a notch in the spacer T, and thus withdrawing the spacer from the leather at the time the awl is sunk deepest into it. T has also a slight vibratory motion in a groove in the spacer-plate Y, limited in one direction by the side of the groove, and in the opposite direction by the eccentric adjusting-pin X, by the turning of which the travel of the spacer may be accurately graduated. The spacer bears against this pin; the pressure of the hand in the direction the machine is to move, will, however, move the spacer to the opposite side of the groove; then, as it is raised by each descent of the awl and peg-driver, it will spring forward against pin X, and, as the awl begins to rise, will descend in the same position upon the leather; and when the awl rises so as to clear the leather, the pressure of the hand in that direction overcomes the spring of the spacer, and moves forward the machine for the next peg. The peg-wood is placed between the part G of the feeder and the spring D. This spring-feeder is operated by the head of the screw V, which holds the awl and peg-driver to

the lower end of the slider, and which projects through a slot in the front of the case, striking, as it descends, against a bend in the feeder, and pushing it back so as to give it new hold upon the peg-wood, at the time the wood is held firmly by the cutters and a clamp E.

With Rice and Whorf's apparatus for lasting and applying soles to shoes, Figs. 1056 to 1058, the sole and the upper are first placed together upon a last A, the upper being made to overlap the outer surface of the in-sole, and affixed by cement. The whole being thus prepared, it is next placed within the clamping-bed B, and the parts of the latter closed. The platen of the press is depressed, to carry the punches on the under-side of die *w* into contact with the parts of the upper which overlap the inner sole, so as to make perforations through them, and either into or through the inner sole. The platen C is then elevated, and cement applied to the outer surface of the inner sole and overlapping parts of the upper. The outer sole is laid upon the cemented surfaces, and the slide G moved so as to bring the die *u* directly over the last A. Next, the platen is to be forced down upon the outer sole, so as to press it closely in contact with the shoe, and expel from between the soles the superfluous cement.

Dinsmoor and Bartlett's instrument for chamfering the edges of shoe-soles is referred to, Figs. 1059 to 1061. The piece of leather is laid upon a flat table, and the blade A and spring-presser H are borne down simultaneously upon the leather, while the end of the lever-gauge G turning upon fulcrum *d* is made to rest upon the table. This done, the cutting-edge *a* of the tool is maintained at such an angle from the table as occasion may require, and the tool is pushed forward upon and around that portion of the leather which is to be chamfered. The frame B is fastened to the knife by means of a wedge *a*.

Figs. 1062 to 1064 show J. W. Hatch's machine for cutting out soles. The cutter is attached to a vertical shaft, which is provided with journals to work in bearings in a slide P, moving in vertical guides in a framing C, and receives its vertical reciprocating motion from eccentric pin *a*, at the end of the horizontal shaft D. The shaft in this machine makes only about three-fourths of a revolution in opposite directions alternately, movement being produced by a treadle F, which is a lever of the first order, with its fulcrum *g* at the rear end, secured to the floor or to a suitable bed-plate; the treadle being connected by a rod *o* with a wrist *b*, at the back of the fly-wheel G of the shaft D.

While the machine is at rest, the wrist is always held in one of these two positions by a weight *r* attached to or cast on the fly-wheel, the weight *r* resting upon one of two fixed standards *f f*. In either of these conditions of the wheel and wrist, the treadle is of course raised. The operator stands in front of the machine, in a convenient position for placing the pieces of leather or other material in a proper manner upon the table H for the action of the cutter; and when he depresses the treadle by his foot, he moves the wheel far enough to bring the weight *r* over the centre of the shaft D; but the momentum the weight has acquired in moving to that point carries it past the centre, and then the pressure of the foot being taken from the treadle, it descends by the force of gravity until it reaches the other standard, thus completing the movement of the wheel. This movement of the wheel brings down the cutter and raises it again, and, just before its termination, it moves the lever E to reverse the position of the cutter by the action of one of two projections *d d* upon one of the prongs *e e* of a fork on the rear end of the lever. The prongs *e e* of the fork are at different elevations, and the projections *d d* at different distances from the shaft D, to correspond with the elevation of the prongs *e e*; so that when the wheel moves in the direction of the full arrow shown in Fig. 1062, the projection *d* may pass under the higher prong *e* and strike the lower prong *e*, thus throwing the lever to the position shown in Fig. 1063; but when the wheel moves in the direction of the dotted arrow, the projection *d* may pass over the lower prong *e* and strike the higher prong *e*, thus throwing the lever to the position the reverse of that shown in Fig. 1063. The movement thus given to the lever takes place just before the weight comes in contact with the standards *f f*, and is just sufficient to give half a revolution to the punch-shaft. To keep the cutter-shaft from turning back too soon, the friction of a bar *h* is applied in a yoke I; on the top of the framing, between the top of the yoke I and the bar *h*, the lever E works snugly, and the bar is forced up against the lever to produce the necessary friction by two india-rubber springs *i i*, one at each end. Stop-screws *j j* are also applied to the yoke I, to stop and regulate the movement of the lever.

Polishing or burnishing the edges of heels and soles with Mollière's machine, Fig. 1065, is performed in the following manner:—The steam passes from the *boiler* through a pipe *x* and into branch pipes *x*, one for each burnishing-tool *p*, and can be let into the hollow shaft *l* and the chamber *p* within the tool *p*, by opening the cock *u*. A number of these tools of slightly varying sizes are arranged in line, and each tool kept rapidly revolving. The polishing is effected by presenting the edge of the sole or heel to the revolving polishing-tool and pressing it gently upon it.

Mollière's arrangement for mounting uppers on lasts is shown in Figs. 1066, 1067. It consists of an adjustable frame I and a thumb-screw G, armed with its tooth-clamp H, which, pressing vertically upon the inner portion only of the heel, holds the *last* securely in its position, and gives free access to the parts of the last on which any work is to be done by the apparatus.

Jackson's machine for cutting out uppers, Fig. 1068, consists of a frame A, to which is attached a cross-head E; this cross-head is raised and lowered by the action of the shaft in the centre, the wheels I and the levers G. The leather is fed in at D on the platen B; the cutters being fixed to the cross-head, and guided in their descent by the indicators T, T.

Fig. 1069 represents Ellison's boot-holder, which consists of a curved arm A reaching from the sole of the foot to the top of the leg L, where it is fixed. This is used in combination with the lever B provided with a last-shaped foot, a handle K and a ratchet C to operate with a pawl D.

Fig. 1070 shows E. M. Dickinson's machine for holding uppers. It consists of a forked clamp B, arranged on the frame A, and hinged at one end. It is operated by the lever C working the rod *d*, the yoke *k*, and the springs *J*, *i*.

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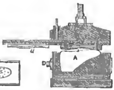
1058.



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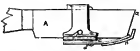

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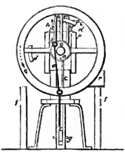

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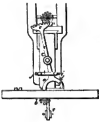

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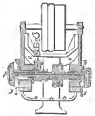

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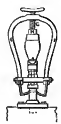

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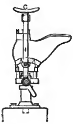

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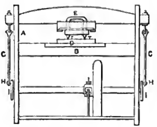

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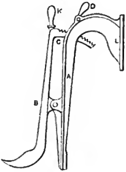

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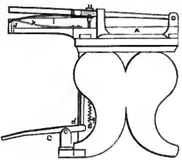
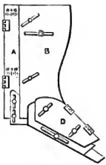


Drew's pattern for cutting boots, Fig. 1071, consists of two pieces of sheet metal A, B, of rectangular form, connected together by hinges; and two other pieces of the same material attached to the former in such a manner as to be capable of being adjusted laterally, one of the ever-pieces D having a foot portion provided with a wing connected to it by means of hinges.

1071.



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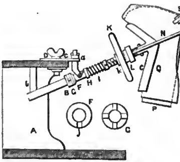
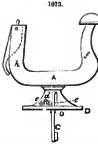


The apparatus, designed by O. J. Warren, for crimping, Fig. 1072, is applied to the bench by a swivel process, which permits the whole to be turned to the right or left as the work proceeds. The curved bar G, which supports the form P, upon which the leather is crimped, has its groove lined with India-rubber Q, which prevents the wrinkling of the leather while undergoing the stretching process. A spiral spring is employed to hold together the two parts of the clutch or yoke N, R, and thus retain the work rigidly in any position; but at the same time adapts the clutch to be disengaged to allow the shaft to be turned to bring the work into convenient positions for the operator. The nut K on the screw *k* of shaft B is connected with the yoke N through the medium of the collar L, so as to allow the yoke to be turned independently of the nut. F is a sleeve on shaft B, provided with a projection *j*, and is used in combination with the notched hub G, the collar H, and the spring I. The coupling by which the shaft B is attached to the bench is composed of a plate C, secured to the bench by a screw D, and provided with a socket *a* to receive a pintle of a fork which is fastened to the sleeve F by pivots.

Gustins' movable jack for boot-making is shown in Figs. 1073, 1074. The arms *h*, *f*, of the frame A, have supports, as *i*, for the toe and heel of the boot, and admit of rotation on a pivot at A. The bolt C and the friction-washer *o* prevent a too ready and easy movement of the yoke A upon the bolt in a horizontal plane. The crank-stop *d*, sliding in the blocks *e e*, with the holes in the segment C, Fig. 1074, permit the instrument to be inclined for working purposes.

1073.



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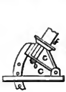

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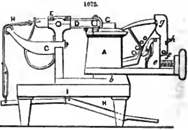
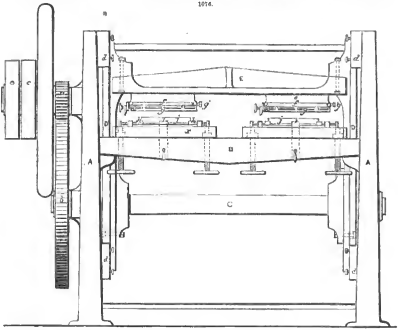


Referring to Fig. 1075, which shows J. H. Belser's machine for shaping heels, *g* is a toe-clamp, *h* its latch fastened to a standard *e*, which is provided with an adjusting screw *f*, and attached to a shoe-holder A. The knife C works through a rocker-tube E by means of the slider D, which is adjusted so as to act in combination with the arrangements shown at H and G. The position of the heel whilst being shaped is shown clearly at C.

Fig. 1076 shows a side elevation of a machine for cutting out and pricking soles and heels, by Craven and Carrack, of Leeds. The parts A are standards or framework braced together by the table B; C is a shaft, actuated by pulleys *c* through intermediate wheels *a*, *b*. Cams on the shaft C impart a reciprocating motion to the slides D working in V-grooves *d*. The slides are connected by the cross-head E, to which are secured the frames *e*, which carry the wood blocks and guides *f* and *g*. The wood blocks *f* are bound with a hoop of wrought iron, and are adjusted in any desired position by means of set screws *g* in the V-races of the frames *e*. The guides *g*, provided with set screws, are to prevent the leather from being thrust too far either laterally or longitudinally. On

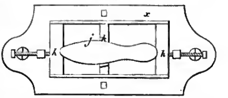
the table B adjustable frames x are placed, which carry the clips h. These clips support the knives j, and may be adjusted by set screws, according to the size of sole or heel required, having V-edges which slide in the frames x. The parts $k\,k$ are two spring-clips to stiffen the knives j.

1076.



The prickers are not shown, but simply consist of a framework of pricks or needles, of the same contour and pitch as the required line of nails, fastened to the wood blocks and piercing the leather in their descent. The knife j and its adjustments will be seen more clearly by referring to the detached plan of the framework x, Fig. 1077.

1077.



The machine being set in motion, a piece of leather is placed by the attendant over one of the knives, the cross-head descending, the pressure of the wood block cuts the sole or heel required, which drops through the knife and the aperture in frame x and table B into any convenient receptacle.

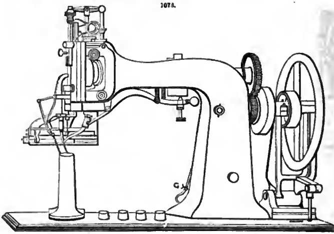
The operation of fastening a sole to an upper was for some time the most difficult portion of boot manufacture by machinery. It has now, however, been greatly simplified by an adaptation of the sewing machine invented by John Keats and W. S. Clark, and termed by them the Crispin Machine.

The leading features of this machine are the combination of a hook and a shuttle, instead of a needle and a shuttle. This arrangement allows of the thread being thoroughly saturated with the wax, which does not get squeezed out, as in passing through the eye of a needle. Further, the hole made in the leather is no larger than the size of the hook, because the hook has no thread in it while piercing the material. Thus, a thicker thread can be used than with the needle. The stitch, which is formed on the surface of the leather, is a twisted lock-stitch, one of the firmest made. The machine is arranged to be driven by steam-power, and the motion can be instantly stopped by a foot-lever at any point of the stitch, so that the workman has the free use of his hands.

Fig. 1078 is a perspective view of the post Crispin, which is used for welted boot sole sewing. Fig. 1079 shows the "arm Crispin," which is employed in heavy work, such as closing heavy uppers, belt-sewing, harness work, and so on. The hook is first fixed by turning the machine by hand until the line cut across the edge of the needle-bar L at the lower end, pointed at by the arrow, is on a level with the bottom end of the slide, and then fixing the hook with its point on a

level with the point of the divider A, care being taken to have the notch which receives the thread at right angles with the arm of the machine. After the large bobbin is charged with thread and placed in position, the cover and hook-plate at the end of the arm are drawn off, and the thread brought over the guide-pulleys until it reaches the pulley B; it is then passed through the eccentric hole in the small gear-wheel. The thread is then drawn forward and passed through the hole in the hook-plate, the cover and plate being replaced. To thread the shuttle, the bobbin has to be placed in it, with the long centre end foremost. The thread is then passed through the upper slot over the bar and through the lower slot, and then through one of the round holes. The operator then places the shuttle upon the slide, and puts down the hinged stop C. He raises the

1078.



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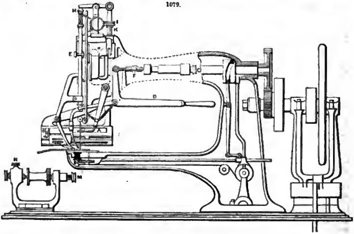


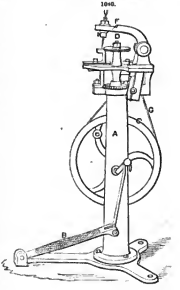
pressure-foot by means of the lever D, and puts the work under the hook so as to be moved from left to right. After the machine is charged with waxed thread, the gas G is turned on, and lighted through the holes in the side of the arm, and also the jets behind the shuttle-race, until the machine is sufficiently warm to make the wax soft, care being taken not to let the flame come in contact with the casting, as this produces soot, which destroys the heating-power of the gas.

A counter-shaft mounted in the frame under the table being put in motion by the driving-belt, the machine is started by pressing the foot-lever, thereby bringing the pulley covered with leather into contact with the internal pulley mounted on the end of the driving-pinion. The moment the pressure with the foot is withdrawn, the machine instantly stops. Suitable tension of hook-thread is obtained by the thumb-screw M. The feeder is adjusted and kept to push in the required

direction by the round vertical bar being pinched with the thumb-screw E; an angle of 45° to the arm is found most convenient. The pressure is adjusted to the thickness of the work by means of the double screw-nut F. The amount of pressure is adjusted by the screw G. The feeder is adjusted to the thickness of the work by turning the screw H. The length of the stitch is regulated by turning the screw I, which is secured by the lock-nut K. To remove the large bobbin, the pin N is taken out; the tension-spring then forces it out.

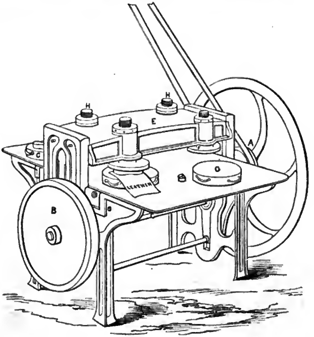
The Pricking Machine, designed by Gimson and Co., of Leicester, is used for making small holes in the bottom of the soles and heels of boots and shoes to receive the rivets. It is contrived so that the distance the holes are apart can be varied according to the number of rivets required. It consists of a standard A, Fig. 1080, through which is a small crank-spindle; the treadle B is attached to the crank, and the driving-wheel C is fixed at the other end of the crank-spindle; the motion is imparted by a cord G from this wheel to a worm-shaft; the worm gives the upright spindle D a revolving motion, and the crank E gives to the arm F a chopping motion; the boy works the treadle with his foot, and with his hands presses the sole against the guide tooth wheel D; this wheel, revolving slowly, moves the sole the required distance as each prick is made by the arm F.

1080.



Gimson's Eccentric Press. — This machine, Fig. 1081, is used for cutting up leather, and is constructed for the use of four men; the cross-head E moves upwards and downwards, and receives its motion from the driving-shaft A, which

1081.



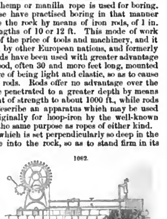
has a pinion attached, and works into the internal toothed wheel B, which wheel is keyed to the eccentric shaft C; the eccentrics are fitted with straps connected to a stretcher—this is fixed to the side D, attached to the cross-head E; the screws H are movable, and can be adjusted by the man to suit the depth of the knife and range of the cutting-tools; wooden blocks G are used to cut upon; the leather is placed on the block, the knife being put on by the man, who also pushes it under the cross-head which comes down upon it and cuts out the sole; the block is then pulled from under the knife, placed on another part of the leather, and the process repeated.

BORING AND BLASTING. Fr., *Action de forer et de faire sauter par une mine*; Ger., *Das Bohren und Sprengen einer Mine in Bergwerken.*

Boring for Minerals.—There is but little difference in the system of boring for minerals or boring for water; the kind of rock to be penetrated does not even cause any material difference to be made in the means or tools by which it is done. A hole of 3 in. diameter is in all cases sufficient for a test on a mineral vein. In the U.S. the hemp or manilla rope is used for boring. This is called the Chinese method, because the Chinese have practised boring in that manner since our knowledge of them. The Germans penetrate the rock by means of iron rods, of 1 in. square or more. These rods are screwed together in lengths of 10 or 12 ft. This mode of work causes the operation to be rather expensive, on account of the price of tools and machinery, and it is not very expeditious. The same method was followed by other European nations, and formerly in this country. In recent works of this kind, wooden rods have been used with greater advantage than iron. These rods are long slender poles of pine wood, often 30 and more feet long, mounted with iron and screwed together; they have the advantage of being light and elastic, so as to cause less concussion and consequently less repair than iron rods. Rods offer no advantage over the rope but that of longer durability, and the earth may be penetrated to a greater depth by means of them than by ropes. The latter are limited on account of strength to about 1000 ft., while rods may be driven down to 2000 ft. and deeper. We will describe an apparatus which may be used either for hemp-rope or wire-rope, which was made originally for hoop-iron by the well-known metallurgist, F. Overman, it being cheaper, and served the same purpose as ropes of either kind.

At A, in Fig. 1082, is represented a log of oak wood, which is set perpendicularly so deep in the ground as to penetrate the loose gravel, and pass a little into the rock, so as to stand firm in its place; it is well rammed by gravel, and the ground levelled so that the butt of the log is flush with the surface of the ground, or a few feet below. Through this log, which may be, according to the depth of loose ground, from 5 to 30 ft. long, a vertical hole is bored by an *auger* of a diameter equal to that of the boring in the rock. On the top of the ground, on one side of the hole, is a windlass, whose drum is 5 ft. in diameter, and the cog-wheel which drives it 6 ft.; the pinion on the crank-axle is 6 in. This windlass serves for hoisting the spindle or drill, and is of a large diameter, in order to prevent short bends in the iron, which would soon make it brittle. In all cases where iron, either hoop-iron or wire-rope, is used, the diameter of the drum of the windlass must be sufficiently large to prevent a permanent bend in the iron. On the opposite side of the windlass is a lever of unequal leverage about one-third at the side of the hole, and two-thirds at the opposite side, where it ends in a cross or broad end in case men do the work. The workmen, with one foot on a bench or platform, rest their hands on a railing, and work with the other foot the long end of the lever. In this way the whole weight of the men is made use of, who work with great ease. The lift of the bore-bit is from 10 to 12 in., which causes the men to work the treadle from 20 to 24 in. high. Below the treadle T is a spring-pole S fastened under the platform on which the men stand; the end of this spring-pole is connected by a link to the working-end of the lever, or the hoop-iron directly, and pulls the treadle down. When the bore-spindle is raised by means of the treadle, the spring-pole imparts to it a sudden return, and increases by these means the velocity of the bit, and consequently that of the stroke downwards.

1082.



The spindle is represented in Fig. 1083, a piece of square cast iron, or wrought iron, of from 200 to 300 lbs. weight for a hole of 3 in. diameter. For larger holes, of 5 or 6 in. diameter, its weight must be increased to 800 or 1000 lbs. At one end of the spindle the hoop-iron or rope is permanently fastened by screws or rivets; at the other end the bore-bit is inserted in a round hole and fastened by a flat key. The spindle may be provided at each end with a head, in the

1083.

form of a cross, but these are unnecessary appendages; a simple square rod of iron, whose diagonal section is equal to the diameter of the hole, is all-sufficient for the purpose. The lengths or parts of the hoop-iron may be made as great as possible, and should be of the best fibrous charcoal iron;

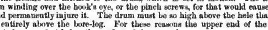
puddled iron, even if fibrous, soon gets brittle in the course of time and work. For a spindle of 300 lbs., hoop-iron of 2 in. by $\frac{1}{16}$ is sufficiently strong; for heavier spindles it may be somewhat stronger. The ends of the hoops are fastened together by means of small rivets and drilled holes, and this riveting ought to be renewed at least every two months, because the repeated vibrations cause the iron to get brittle, which is the case at the joints more than in the run of the iron. At the upper end, where the hoop is fastened to the lever, there is a length of hoop-iron nearly equal to one length or part, at one end of which is an eye permanently fastened; this fits in a hook at the lever, and also in a hook at the drum. This loose part of the strap is fastened to it by means of pinch screws, as shown in Fig. 1084; by this means the hoop may be made longer and shorter, as

1084.

the bottom of the bore sinks down; the letting out, of course, can be performed only while the work is stopped. If we want to let out while the treadle is in motion, which is necessary in soft rock, a screw about 1 ft. long is provided at the end of the treadle, which may be turned while the machine is in operation. The bore-bit has been shown in Fig. 1083 as it is fastened to the spindle. This is a simple, flat chisel, whose edge is steeled with good cast steel, and a little rounded, so as to play always in the centre of the hole. If the chisel is too round, or pointed in the middle, the hole is liable to get narrow in the bottom; if the edge is straight, the hole generally widens with its depth. Other forms of the bit are of little use, they merely cause trouble and loss of time. The bit must be fastened very firmly in the spindle, and the shoulder of it fit closely to it, or both are liable to get out of order. When the spindle is to be lifted from the pit, the end of the hoop is taken from the treadle and hitched to the drum, which is set in motion. The hoop must be prevented from winding over the hook's eye, or the pinch screws, for that would cause short bends in the iron, and permanently injure it. The drum must be so high above the hole that the spindle may be lifted entirely above the bore-log. For these reasons the upper end of the latter is frequently found to be some feet below the surface of the ground.

The operation of boring is simple; when the hole through the bore-log is sunk, the spindle is let down, hitched to the treadle, and the latter set in motion, which labour two or three strong men can readily perform. If but 10 or 12 inches lift is imparted to the bit, from 30 to 40 strokes may be made in one minute. If a good hop-pole is appended, from 30 to 45 strokes may be made by men, and from 80 to 100 by a steam-engine. The rock is thus penetrated by repeated blows, of which from 50 to 100 are sufficient to sink 1 in. deep in soft slate and shale; from 500 to 1000 in sandstone rock, and from 10,000 to 20,000 strokes in graywacke or gneiss. Even as many as 30,000 and 40,000 blows have been struck to penetrate 1 in. deep in hard graywacke. Iron pyrites are almost impenetrable; and the best plan is, if the vein is but a few inches thick, to break it by heavy strokes of a blunt steel point, directed so as to break off pieces from the mineral. When a certain depth, say 1 ft., or 2 ft., is penetrated, the *débris* of rock, ground into dust, and floating as fine sand in the water of the hole, must be removed, which is done by the pump; this instrument is represented in Fig. 1085; it is a sheet-iron cylinder, of from 3 to 4 ft. long, and ¼ or ½ in.

1085.



smaller in diameter than the diameter of the hole, so that it may pass down easily; it is provided at its bottom with a strong iron ring riveted firmly, and soldered to the sheet iron; upon this ring is fitted a valve, which may be a poppet-valve, or a ball, or, what is equally as good as any, a trap-valve formed of a piece of sole-leather or strong india-rubber, provided with a piece of metal to make it heavy and shut close. Metal valves do not shut well, for often coarse sand gets into the pump, which does admit of a hard valve to shut, while a light valve of soft matter will press the sand out, or at least close sufficiently tight to prevent the mud from flowing out. This bucket is gently let down upon the bottom of the well by means of a small rope, a wire-rope, or a hoop-iron tape; it is then rapidly moved up and down a few times by hand, and raised. This latter operation is best performed by a small windlass, erected purposely for the pump. The strong windlass is too heavy and slow for this operation. When the pumping has been repeated two or three times, we may suppose at least all the heavy sand is removed from the bottom of the well. Pumping ought to be performed after the water has been for a while at rest, early in the morning or after meal times. This operation is very simple and effectual. The pump in being raised rapidly from the bottom of the well causes a strong current of water to pass vertically down; this stirs all the heavy sand in the bottom, and even pieces of iron and steel which may accidentally fall into the well, and brings them into the pump. Many other devices have been proposed for this purpose, but we know of nothing superior to this simple machine. See Artesian Wells.

Where a steam-engine is at command, as is generally the case at salt-wells, the operation may be performed with ease, and cheaply. Is a water-wheel or a mill at the place where a hole is to be sunk, the expenses are very small, one man attending the whole operation. In most cases it does not make much difference where the hole is driven down, if not too far off from the outcrop, so as not to miss the ore deposit. If the extent of a mass or vein is known, and we want merely to know the depth from a certain point, in order to calculate the expenses of a shaft before we sink it, it may be profitable to erect a steam-engine for boring, in case the depth is considerable. Horses or mules may be also employed at a common horse-whim to do the work; this, however, is not much cheaper than manual labour, but the work may be done faster. In case a steam-engine, water-wheel, or horse-power is used, a shaft with *cams* or *tappets* must be provided, which latter press upon the treadle instead of the feet of men. If in this arrangement the shaft with tappets

can be so arranged as to be moved farther off, or closer to the treadle, it is recommended; for if changing stratified rock is met with, different heights of stroke or change of lift is required; soft rock or slate cannot bear as strong blows as hard rock. In this case the spring-pole must be strong enough to balance the whole weight of spindle, and rope or iron belt, so as to keep it suspended when at rest. The large drum for winding up the rope may serve as an axle for tappets; the latter are then fastened to the large cog-wheel, and lift the treadle directly, or, what is the same, the end of the rope or iron belt. The crank-shaft, on which the handles are, serves in this case as a driving-shaft, driven by pulleys and belt from the engine, the water-wheel, or horse-power.

Turning the spindle, or bit, is a necessary operation which is much favoured by a hemp-rope, not so much by a wire-rope, not at all by hoop-iron, or by rigid bars of iron or wood. In striking the bottom of the well by the sharp chisel, it is to turn around the axis of the spindle, or its own axis, in order to cut a round hole; the more rapid this operation is performed, the more correct is the work, and the faster it proceeds. The hemp-rope, in lifting the spindle, is stretched, and endeavours to untwist, setting the spindle in a rotary motion, in which it continues until its return to the bottom of the well. At the head of the spindle there is a loose eye, or swivel, in which the rope is fastened: the rope will return, when slackened, and assume its twist again. This operation, however destructive to the rope, performs the rotary motion of the bit more perfectly than any other means. The rigid rod, and the hoop-iron or wire-rope, must be turned by hand, if no machinery is expressly prepared for the purpose. If turned by hand, which is done by means of a cross-handle above the bore-log by a small boy, it ought to be done rapidly; each stroke ought to have more or less than a whole revolution. If this operation is not properly attended to, the bit is very apt to cut rifles or flutes, particularly in stratified rock, which are very troublesome in the progress of the work.

Accidents.—It may happen that the belt, rope, or the rod breaks, or the bit or spindle is injured, and leaves parts of steel and iron in the hole. If the latter is the case, and the pieces broken off are not too large, the most expeditious plan is, to take a dull hard bit and pound the iron into such small pieces as may be removed by the pump. Is the belt or rod broken, the operation is not difficult, but in the latter case tedious. The hoop-iron, or a hemp or wire rope, is easily drawn up, which is most conveniently done by the following machine. In Fig. 1086 is represented a pair of tongs, which are fastened to the main rope R, which is slackened in letting down the tongs. W is a single wire, or a small hemp-rope, such as a bed-cord, or the pump-rope. When the tongs are so far down as to be below the broken end of the rope, the wire W is pulled so as to open the tongs, after which the belt R is turned round its axis. The lips L of the tongs, forming a basket, sweep now the circumference of the hole, and draw the broken rod into their grasp; when such indications are perceived at the upper end where the workman is turning the belt R, the wire W is suddenly slacked, and the sharp steel lips will bite the iron or hemp; the whole is now lifted by the windlass, and the broken ends mended. With a wrought-iron spindle, hardly anything can happen; a cast-iron spindle may break; but if made of a square form, there is so much room on the four flat sides as to admit two sharp-pointed bits of the tongs, which may fasten in it sufficiently so as to lift it. More vexatious than such breaks is the crumbling of rocks, particularly if these rocks are hard or tough. If the spindle has a little space at its upper end, and a piece of rock falls down from a higher place and wedges in between the spindle and the walls of the well, it causes often long delay and much labour to remove such small stones. Is the treadle moved by men, such impediments are generally observed before the rope breaks, and may be made less disturbing when attended to in proper time; but if a steam-engine or other power is at work, it will tear the rope or rod, and cause the spindle to be tightly wedged. In order to prevent the breaking of the rope, that part of the lifter where the rod is suspended must be made so weak, that, when the cam lifts it, and it is heavier than the weight of rope, spindle, and bit, it will break and prevent by its rupture the breaking of the rope. Is the latter not injured, there is generally not much difficulty in getting the spindle out. At the top of the bore-hole must be always a certain mark, which indicates exactly the depth of the well by the length of the rope; if the spindle is in any way raised above the bottom, we may know it by this mark, or by the position of the treadle. In this case, gentle up and down motions at the rope will generally loosen the spindle so as to make it play; its going down to the bottom, however, ought to be prevented, for which reason the end of the rope is laid on the windlass, and the rope so far stretched as to prevent its sinking to the bottom. By means of the treadle or by hand, the apparatus is now kept in motion and gently raised by the windlass. If these means will not succeed, force at the windlass is tried, but never beyond the strength of the rope so as to break it. If this also fails to lift the spindle, an iron rod, with a blunt end, which cannot penetrate between the spindle and the walls of the hole, is let down by means of the pump-rope, and gentle blows are imparted on the head of the spindle; this will either start the spindle, or will crush the pebbles which hold it. Is the rope or rod broken, these operations must be performed with more caution, so as to prevent forcible lifting; for when the tongs have hold of the broken end of the belt, that is never so firm as the rope or belt itself.

1086.

Most of the accidents are caused by loose stones, gravel or pebbles, crystals or pieces of slate, from cavities above. Most of the rocks contain caves, or nests of crystalline loose matter, which is thrown down by the motion of the water and the vibrations of the boring instruments. In these cases, pipes of sheet iron, of copper, or of other metals, have been inserted in such places;

which operation, however, is expensive, tedious, and not quite safe; much ingenuity has been expended on inserting such pipes. In all cases of boring, the mouth of the well, or upper part, ought to be well secured by the bore-log; it should reach down into the solid rock, and prevent any dropping of gravel from above. When, in the course of the descent, cavities are penetrated which prove to be filled with loose matter, threatening to obstruct the progress of the operation, the best plan is to cut through such a cavern, if possible, and reach the solid rock again. If this cannot be accomplished, the chisel is driven down as far as possible, and the cavity filled by cement, which is closely rammed in by a plunger. The cement for this purpose is mortar cement, also called Roman cement, which is made of impure limestone, such as is found in the coal regions and marl beds, in the form of lumps imbedded in marl, clay, or shale. This kind of limestone, when burned, does not slack; it must be ground fine, and is then mixed with water to a stiff mortar. If no such impure limestone can be obtained, common lime is mixed with burnt and finely-ground iron ore, burnt marl, or burnt ferruginous shale, pumice-stone, or any kind of volcanic porous rock. The whole, lime and admixture, of which latter about 40 per cent. of the lime is used, is ground together and mixed with water so as to form a stiff mortar. Cement mortar will harden in the course of a few days under water; but it is advisable to make a trial of it before it is put down into the well. This mortar is filled in canvas or muslin bags, of such a size as to sink gently down to the bottom of the well. A number of filled bags is let down, and then the plunger,—which may be the spindle,—is pressed upon them to break the bags, and drive the mortar into the cavity. This is gradually filled entirely with mortar, and then left at rest for some days. Part of the mortar is, in the meantime, immersed in water, above ground, in order to observe its progress of hardening. When the mortar is hardened below, it is penetrated by the bit, and a round hole bored through it, which forms now a pipe of cement, which will effectually prevent sand or gravel from running down and causing disturbances in the operations.

In all cases of sinking a well or a bore-hole, the progress of the work should be recorded in a journal from day to day; and each day, or at each pumping, a part of the bore-meal, or the coarsest *débris*, saved for future examination. The latter operation is simple, and causes no loss of time. When the pump is raised, the contents of it are cast into a fine wire sieve, or into a bag of fine wire gauze, which is made to contain all the contents of the pump. The water and the fine parts of rocky matter will pass through the meshes of the sieve and float off, while the coarser parts remain. A part of the sediment is saved in a paper, or in a small box, and it is marked with the time and depth, when and where obtained, for future reference. These evidences, when put together, form the elements of a section of the rock strata penetrated by the well, in that particular spot, and are suitable objects for publication. Any geologist can form, by these means, a profile of the rock, or general formation. Many hundreds of *artesian wells* are now sunk, and have been sunk in times past in our country; these would furnish means for obtaining a correct insight of the geology of those places where the operations are performed. For the want of such records, the information arising from the labour of boring, at a particular spot, is lost to the community and the science of geology.

Any size of hole will answer the purpose of the miner; and if 2 in. in diameter could be sunk, it would be sufficiently wide; but this cannot be done; the form of the tools, pump, and rope, require at least 2·5 in. All complicated tools, such as cross-chisels, rasps for widening, and similar instruments, are to be avoided. They are expensive, both in first cost, repair, and cause loss of time. The simple flat chisel will form a perfectly round hole; when attended to in turning the rope, it will make the hole wide enough all the way down; if frequently changed and sharpened, it works easy and fast. A chisel and a good pump, a safe rope, and good tongs, are all the implements requisite for sinking a hole of 2000 ft. deep.

We give an example of boring for minerals, from the 'Transactions of the North of England Institute of Mining Engineers,' vol. vii. The paper which furnishes this example was read by the justly-celebrated Nicholas Wood; we give it and the discussion thereon, without any material alterations, to show the baseless fabric upon which the so-called science of geology is made to rest.

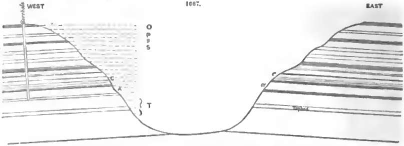
Nicholas Wood, President of the Institute of Mining Engineers, on the Deposit of Magnetic Ironstone in Rosedale.—In John Marley's very elaborate and very able account (says *Wood*) of the Cleveland Ironstone District, communicated to this Institute at its meeting of June, 1857, and published in vol. v. of the 'Transactions,' he states:—"The only special district to which I think necessary now to allude is the Rosedale Abbey district, the ironstone from which has attracted a large amount of attention, on account of its large percentage, immense deposit, and magnetic properties."

Marley then gives a history of the discovery of this bed of ironstone, its position in the series, as well as in the district generally, and adds all the information which had then been elicited with regard to the particular features and character of such deposit, which he illustrates by a diagram, showing the explorations which had been made by drifts and pits towards such elucidation; and he then concludes by saying:—"I have no doubt that this seam is the same as the seam at the point *A*, Fig. 1087, as also the same as that found on the east side of Rosedale, in Captain Vardon's property, of varied thickness, as well as the same seam as that at Grosmont, Fryupdale, Swainby, and Boltby, known as *the top seam* of Cleveland—the nine inches of coal in the pit sunk agreeing with *Beckhole*, near Grosmont, in particular; so that the only doubtful point is as to the portion from the outcrop at *A* to the so-called magnetic quarry; the most feasible solution being that it is a disjointed patch of the regular seam, known as the *top seam*, and not a vein, as has been said; and, with all deference to the parties who have had more opportunity for examining this district than I have, I propose leaving the *extent* of the *magnetic and extra percentage* tract as an *unsolved problem*, as it may vary from one or two acres to any indefinite extent, not being at all proved to the south."

This is a very clear and correct account (says *Wood*) of the information then existing on this

deposit, Marley's opinion being that it represented the top seam, as developed at Grosmont, Fryupdale, Swainby, and Boltby.

1087.



Reference:—O, Shale and ironstone ramble. P, Brown and grey sandstone. 9, Coal and shale. S, Shale and sandstone. T, Sandstone; top bed, of iron and lias respectively, not proved by the bore-hole.

A Section of the Strata at Grosmont is given by Marley as follows:—

	Ft.	In.				Ft.	In.
Sandstone	25	0			Ironstone band and shale	29	0
Ironstone, top seam	12	0			"Pecten" band, part of the Cleveland thick seam	5	10
Lias shale	92	0	198	0	Shale	17	4
Various strata, not identified	51	0			"Avicula" band, Cleveland seam	6	4
Lias shale	55	0					

Another section near Grosmont gives the top seam 11 ft. 6 in., then 187 ft. of shale and ironstone, and then the Cleveland band.

The Section at Fryupdale is as follows:—

	Ft.	In.		Ft.	In.
Freestone	55	0	"Pecten" band, Cleveland main seam	6	0
Top seam	12	0	Shale	30	0
Jet, cement, and alum rocks	202	0	"Avicula" band, Cleveland main seam	4	4
Shale	60	0			

The Section at Swainby is as follows:—

	Ft.	In.		Ft.	In.
Shale	13	0	Shale	132	0
Top seam	23	0	Cleveland main bed	9	3

And at Felix Kirk, near Boltby, the Section is:—

	Ft.	In.	Ft.	In.	
Brown, yellow, &c., gritstone			0	0	
Boltby and Rosedale iron rock			7	0	
Alum shale, or upper lias shale			116	0	
Upper band of nodular ironstone	0	7			Type of Eston or Cleveland main seam.
Thin seam of soft shale	3	0	4	1	
Lower band of nodular ironstone	0	6			

Section of Strata in the Hills at Swainby Mines.

			Ft.	In.	
Soil, &c.			3	0	
Freestone			24	0	Near the limekiln this is 100, with 9-in. ironstone balls in it.
Slaty coal	0	9			
Shale	1	0			
Sandstone	4	0			
Slaty coal	0	9			
			6	6	
Shale			5	0	
Coarse freestone			3	6	
Shale, with occasional nodules of ironstone			13	0	
Ironstone, good	2	0			
Ironstone	21	0			
			23	0	
Carried forward			78	0	

Section of Strata in the Hills at Swainby Mines—continued.

		Ft. In.	Ft. In.	Ft. In.	
	Brought forward			78 0	
	Shale			132 6	
Not Wrought	Ironstone		2 8		
Not Wrought	Shale		1 0		
			3 8		
	Ironstone	2 5			
	Shale	1 8	5 7		
	Ironstone	1 6		9 3	Scarthnick bed or seam.
	Shale			9 3	
	Ironstone		1 3		
	Shale		0 6		
	Ironstone		1 3		
				3 0	
	Shale			16 6	
	Ironstone			1 6	
	Supposed shale, but unproved down to the level of the bottom of Crook beck			335 0	
				585 0	

Section of the Strata at Eston Nab, showing the top seam, and the main or Cleveland band, where the latter is in perfection.

		Ft. In.	Ft. In.	
Approximated.	Soil, and other strata unproved		50 0	
Approximated.	Freestone		60 0	
Approximated.	Shivery post, patches of jet and clay		54 0	
Seam called the "Top Seam."	Nodular ironstone	0 1		
	Shale	2 3½		
	Nodular ironstone	0 3		
	Shale	0 7		
	Nodular ironstone	0 0½		
	Shale	0 10	6 0	Measured working section.
	Nodular ironstone	0 1		
	Shale	0 6		
	Nodular ironstone	0 1		
	Shale	0 6		
	Ironstone band (varies)	0 9		
	Aggregate of ironstone, 15½ inches.			
Approximated.	Lias shale, including jet rock at bottom		210 0	
	Ironstone band	0 2		
	Shale	2 5		
	Ironstone band	0 2		
	Shale, mixed with nodules of ironstone	1 10	10 0	Measured section.
	Ironstone band	0 3		
	Shale	1 0		
	Shale, inclining in some parts to a fire-clay nature	4 2		
	Aggregate of ironstone, 9 inches.			
Cleveland Main or Thick Bed or seam of Ironstone.	Top block, left as roof	0 11		
	Parting regular at outcrop, but not so after.			
	Second block (left as roof near outcrop)	2 3		
		3 2		
	Main parting (a good one near the outcrop, but lost farther in).			
	Main block and uniform	12 0	17 0	Measured section.
	Parting (lost after leaving outcrop).			
	Bottom block (varies)	1 10		
	Shale	7 0		
	Ironstone band (called 2-ft. band) ..	1 8	15 6	
	Shale	6 0		
	Ironstone band	0 10		
	Blue shale		36 0	
	Various beds of grey post and metal stone, &c. ..		93 6	
	Total		552 0	

The main features of the sections given by Marley as assimilating to the Rosedale bed, are,

1st. The top seam, varying from 12 to 23 ft. in thickness.
2nd. Lias shale and other strata, 132 ft. to 220 ft.
3rd. The Cleveland main band, 9 to 12 ft.

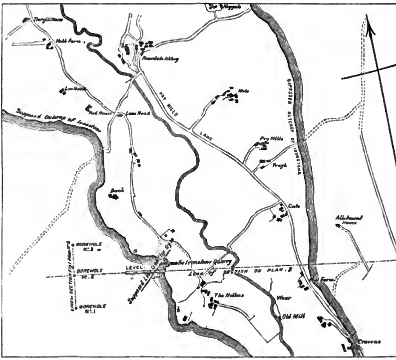
But in all these sections there are no beds of ironstone between the top seam and the Cleveland main band.

Bewick, in a paper presented (says *Wood*) to the Institute, and printed in vol. vi. of the 'Transactions,' gives drawings, and an account of the deposit of Rosedale, and concludes with these remarks,—"My object in thus troubling the members of this Institution with the foregoing remarks is twofold. First, to show that the iron ore of Rosedale, instead of being a large mineral field, as was first asserted, and still believed to be so by many, is nothing more than a volcanic dyke; and secondly, that the ironstone lately opened out in this locality is not, as it is reputed to be, the main seam now being worked in the Cleveland and Grosmont districts, but it is my opinion, if Marley will permit me to say so, the top seam."

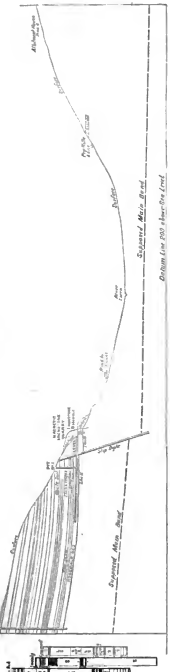
I shall now (observes *Wood*) give an account of the operations concluded by Professor Phillips and myself towards the investigation and development of this bed of ironstone.

The first discovery of this deposit of ironstone was at a quarry on the south-west side of the valley of Rosedale, about a mile south from Rosedale Abbey, and shown, Fig. 1088. When this

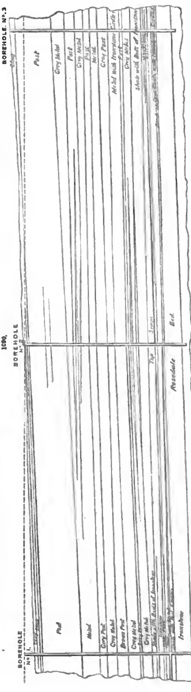
1088.



quarry was opened out it was found to consist of apparently a confused mass of ironstone boulders of an ellipsoidal structure, and of gigantic size, often 3 or 4 ft. in diameter; the central part of these boulders being generally blue, and consisting of a solid dark oolitic magnetic iron ore, with, in many cases, sandy and solid ironstone crusts around it; and, in receding from the centre, the iron ore becomes paler, alternating with dark brown purplish layers; the layer then becomes pale brown, and the magnetic quality is lost. In most cases, however, the nodules are quite solid, and a slight stratification exists, though very obscure; and in several cases, likewise, the oolitic structure is merged into compact brown iron ore. In some parts also, where exposed to the water and to the weather, the iron ore is partly washed away, and a gritty ferruginous crust remains. These great variations do not occur where the ironstone is under cover, or covered by other strata, but appears to assume those different phases in consequence of its extreme susceptibility to change by exposure to air and water; and it is somewhat remarkable that the magnetic property is



Reference to side sections :—F, Freestone. S, Shale. I, Ironstone. G, P, M, Grey post and metal. L, S, Lias shale. S, P, Shivery post. C, Coal.



strongest where the mass is thickest, and scarcely shows any magnetism in places where it is thin, or where it has little cover, and, consequently, more exposed to decomposition or change.

The great characteristic difference of composition between this ironstone and the top and main band of Cleveland is, the entire absence of shells, the structure being entirely of an oolitic character, being entirely composed of small round concretions of iron ore, cemented together with extremely thin siliceous or arenaceous films, and in its magnetic properties exhibiting polarity, and likewise in its greater richness than the ordinary ironstone of Cleveland.

This quarry has been excavated so as to form a face of 60 ft. in thickness; to which must be added 11 ft. of blue magnetic stone, 2½ ft. red ironstone, slightly magnetic, bored down below the bottom in magnetic stone, and 3 ft. of shale.

Soon after the quarry was discovered, it was thought advisable to drive a drift into the side of the hill, to ascertain the extent of this deposit, the quarry being about 600 ft. from the bottom of the valley, and about 300 ft. below the utmost level range, or plateau of moors, lying on the south-west side of the valley. This drift, together with a pit sunk upon it, is shown by a drawing in Marley's paper. Since then, it has been driven to a much greater distance, and three *bore-holes* have been put down from the surface to the Rosedale bed of ironstone.

Fig. 1088 shows the position of this drift, the distance and direction in which it has been driven into the hill, and also the position of the three bore-holes and the quarry. And Fig. 1089 also shows the section of the same drifts, and the section of the borings, together with their depths from the surface, and the beds of ironstone which they have proved. I have carried such section across the valley, for the purpose of showing the position of the ironstone band on the opposite side of the valley.

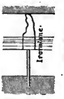
Fig. 1090 shows, on a larger scale, the strata bored through in the three bore-holes above alluded to, and the ironstone beds which they have proved; Figs. 1091 to 1093, bore-holes, Fig. 1094, facing drift, and Fig. 1095, side drift—show the thickness of the lower bed of ironstone in the several bore-holes in the face of the drift, and also in the side of the drift.

1091.

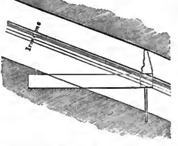
1092.

1093.

1094.



1095.



It is necessary to remark that, where the drift was first set away in the side of the hill, it met with shale, and it continued in shale for a distance of about 80 yds., when the ironstone was found. The drift continued in the ironstone for a distance of 180 yds. farther, making a total distance of 260 yds. from the face of the hill. Fig. 1089 is a section of the ironstone at the face or farthest extremity of the drift, showing an entire thickness of 32 ft. of ironstone, namely, 6 ft. 2 in. of drift, 11 ft. 9 in. above the drift, and 14 ft. below it. And, what is important to mention, the ironstone was here distinctly stratified, as shown by the lines across the section, Fig. 1094.

400 yds. in advance of the extreme end of the drift, and 660 yds. from the side of the hill, a *bore-hole*, No. 2, Fig. 1089, was put down; and at right angles to the line of this bore-hole from the drift two other bore-holes were put down from the surface, as shown, Figs. 1089, 1090, each 200 yds. distant from No. 2 bore-hole, or 400 yds. separate; and the following are sections of the strata passed through in these bore-holes.

Account of the Boring No. 1, *Fig.* 1090, *or South Bore-hole, on Rosedale Moor.*—1858.

No.		Fms.	Ft.	In.	No.		Fms.	Ft.	In.
						Brought forward	39	4	9
1	Clay	0	5	0	13	Ironstone, magnetic	0	5	0
2	Metal or shale	1	1	0	14	Shale mixed with ironstone	1	0	9
3	Brown freestone water ..	12	5	6	15	White post	0	2	4
4	Metal or shale	6	1	6	16	Shale	1	1	0
5	Brown and grey post	2	0	0	17	Dark metal	0	3	0
6	Grey metal	3	2	0	18	Shale with post girdle ..	1	5	3
7	Brown and grey post	3	4	8					
8	Grey metal	3	4	9			45	4	1
9	Grey post	0	5	6	19	Ironstone, magnetic	5	2	0
10	Grey metal	3	1	10	20	Inte. shale	0	1	6
		38	1	9		Total depth, fathoms ..	51	1	7
11	Ironstone, magnetic	0	4	0					
12	White shale mixed with ironstone	0	5	0					
	Carried forward	39	4	9					

Account of the Boring, the Middle Hole, or No. 2, Fig. 1090, *on Rosedale Moor.*—1857.

No.		Fms.	Ft.	In.	No.		Fms.	Ft.	In.
1	Freestone ramble	0	3	0		Brought forward ..	37	3	3
2	Metal	0	4	0	19	White post	0	1	3
3	Brown post 5 2 0				20	Metal	1	3	6
4	Grey post 1 3 0	12	1	0	21	White post	0	3	3
5	Brown post 5 2 0				22	Metal ironstone girdles ..	2	5	0
6	Metal	5	3	0					
7	Post with water	0	5	0			42	4	3
8	Metal	0	5	0	23	Ironstone	2	1	3
9	Coal	0	0	4	24	White post mixed with whin	1	2	0
10	Metal	0	2	6	25	Metal with ironstone girdles	1	1	6
11	White post with water ..	0	3	0	26	Black metal mixed with ironstone	0	4	0
12	Metal	2	1	6					
13	Grey and brown post	2	3	0					
14	Metal	3	2	0			48	1	0
15	Brown post	2	3	6	27	Ironstone	5	2	0
16	Metal	3	5	0	28	Inte. grey shale	1	1	0
17	White post	0	4	0					
18	Metal	0	5	5		Total depth, fathoms ..	54	4	0
	Carried forward ..	37	3	3					

Account of the Boring, No. 3 Hole, Fig. 1090, *or North Hole, on Rosedale Moor.*—1858.

No.		Fms.	Ft.	In.	No.		Fms.	Ft.	In.
1	Clay	1	1	0		Brought forward ..	40	3	0
2	Brown post	11	5	0	14	Ironstone	0	3	0
3	Grey metal	4	1	0	15	Shale, mixed with ironstone	0	5	9
4	Brown post	3	3	6	16	Gullity post	0	0	9
5	Grey metal	2	0	0	17	Ironstone, magnetic	0	5	6
6	Brown post	2	1	0	18	Light-coloured ironstone ..	0	3	0
7	Grey metal	2	5	0	19	White post, mixed with whin	1	1	0
8	Brown or grey post	3	0	0	20	Ironstone, magnetic	0	3	0
9	Grey metal ironstone girdles	4	1	0	21	Grey shale, mixed with ironstone and post girdles ..	1	2	6
10	Grey post	0	4	6	22	Black metal	0	2	6
11	Grey metal	2	5	6					
		38	3	6			47	0	0
12	Ironstone, magnetic	0	4	6	23	Ironstone, magnetic	4	5	3
13	White shale, mixed with ironstone	1	1	0	24	Inte. shale	0	4	0
	Carried forward ..	40	3	0		Total depth, fathoms ..	52	3	3

It will be seen, therefore, that for a distance of 580 yards from the pit, No. 1 on the section, Fig. 1089, to the boring No. 2 on the same section, the thickness of this bed of ironstone is nearly the same, and that this is the case likewise at the other two bore-holes, Nos. 1 and 3, at right angles to the above line of section, the respective thicknesses being as follows:—

	Ft.	In.		Ft.	In.
Drift	32	0	No. 2 bore-hole	32	0
No. 1 bore-hole	32	0	" 3 "	29	3

These borings and sections show two distinct beds of ironstone, stratified with great regularity; and they prove most conclusively that neither of them is at all like what Bewick terms "nothing more than a volcanic dyke."

It will be seen by the map of the district, Fig. 1088, that a border is traced around the edge of the valley; this is undoubtedly the outcrop of what is called the "top seam" of ironstone, as it can be traced south and east into Eskdale, and towards Grosmont and Fryupdale; and also north towards Swainby and Bolthy, in which localities Marley has given sections of the top seam, and also of the Cleveland main band. Supposing this outcrop in the Rosedale valley to be the top seam, then the upper bed in the sections, Figs. 1089, 1090, is unquestionably the top seam likewise; and we there have a bed of ironstone upwards of 30 ft. thick, lying parallel to and strictly conformable with the "top seam" (and separated therefrom only by a thin bed of shale), of an entirely different character from either such top seam or the main band of Cleveland.

I have (says *Wood*) laid down on plan, Fig. 1089, a section of the strata given by Marley, at Grosmont to the south-east, and at the Swainby mines to the north; and I have added the section at Eston Nab. It should be observed, also, in corroboration of the upper bed of ironstone, Fig. 1089, being the top seam, that a bed, or rather three or four beds, of ironstone intermixed with shale occur in the brook of Rosedale and crops out in the bank, which is generally believed to be the representative of the Cleveland main band, though the ironstone is very inferior, and not workable. I have laid down on the section, Fig. 1089, the position of this bed of ironstone, which agrees pretty well with its position in the other sections, making allowance for the variation in the thickness of the lias shale as found in the several localities.

I have (observed *Wood*) likewise, in Figs. 1088, 1089, shown the position of the quarry, which

appears to have slipped down below the level of the beds, as shown by the drift and borings. This appears to have been occasioned by a slip-dyke which crosses the drift near the pit, as shown on the plan, Fig. 1088. It will be seen by this plan that the drift passed through alluvial soil and shale up to near the pit, when this dyke was crossed and the ironstone cut, as shown on the plan. This dyke is supposed to run in the direction shown on the plan, crossing the drift near the pit, and throwing the strata down on the south-west side, and, consequently, the strata comprising the quarry; and it appears that the quarry itself is much broken, and has very much the appearance of a disjointed slip, the elliptical nodules being in a mass of confusion, as shown on the plan.

It has been supposed by some parties that this dyke has given the magnetic character to the ironstone; but it is well known that the character of the ore must be changed from a peroxide to a protoxide to become magnetic, which the crossing of the dyke through the strata could scarcely accomplish; and then we have the entire absence of shells in the lower bed, while the matrix of the upper bed or top seam is entirely calcareous and filled with shells. The concretionary nature of the stone, and the much greater percentage of iron produced by this deposit over that of either the top seam or the Cleveland main band, are also characteristic of this bed of ironstone; the analysis given by Marley of the Rosedale stone being upwards of 50 per cent. of metallic iron, while the top seam and main band are about 32 to 35 per cent.; and the produce of a large quantity smelted at Consett gave 55 per cent. from the calcined ore, and 45 per cent. from the raw stone.

Whatever opinion may, therefore, be formed of the cause of this deposit, we certainly have the fact that, for a width of 400 yds. and a length of 580 yds., we have a bed of ironstone highly magnetic, of an almost entirely uniform thickness, totally different in its mineralogical character from the ordinary stone of the district, and yielding in produce nearly 20 per cent. more iron in the furnace. To what extent this bed may exist beyond the extent already proved will be the subject of further investigation; but it will be a very extraordinary anomaly in geology if a bed of such uniform thickness should not extend to considerable distances. It has been stated that a similar bed has been discovered in other and distant localities; not being myself cognizant of the facts, and my information not being very precise, I abstain (says *Wood*) from giving such information at present. The importance of such discoveries are of too great interest in the district, and too valuable in a commercial point of view, to remain long unexplored, and therefore we may hope that at some future period the Institute will be favoured with an account of such deposits.

The President's paper on the Rosedale Ironstone having been read, a discussion thereon was taken.

Bewick said the magnetic ore in the quarry was a casual deposit in the shape of a dyke or vein.

Marley.—I understand, since I was at Rosedale Abbey, that which the President stated to be the top seam had been discovered in a regular stratified state on the south side of the magnetic quarry. At the last discussion we had on the subject, I admitted if that bed of ironstone had been discovered keeping on its uniform rise and dip, from the north side of the quarry to the south, I had been mistaken in supposing the magnetic seam to be the same as that of the seam then discovered on the north side of the quarry. Then, as to whether it was a vein or a bed, or whether, what I supposed at the last meeting, it was an overflowing between soft strata, similar to "flats" in lead veins, I had not an opportunity of forming an opinion, for want of the *three bore-holes*, which have now been given.

The *President.*—What you stated was quite correct. The top seam had not then been found on the south side of the quarry. It is now found on the south side as well as the north side; but I do not think we have yet discovered the magnetic stone on the south side of the quarry, except in the drifting and borings.

Marley.—When I made my examination, preparatory to reading my paper, the top seam at the point *A* on Fig. 1087, therein referred to, was lost, and no continuation was found south of the magnetic quarry; but, by competent witnesses, I have been informed it is now found south of the said magnetic quarry. But, if the magnetic stone is a bed, it is extraordinary so large an extent of country should give no trace of it, as at Grosmont and other places we have not the slightest trace of it. At Ingleby they are putting three bore-holes down, with a view of proving the existence or otherwise of the magnetic ironstone there. They are now, I believe, past the top-seam position, but have got nothing but shale yet. These borings will prove about 100 fathoms of strata. I have hitherto been of opinion that the round particles, in the specimens of magnetic ore, are oolitic shells.

The *President, N. Wood.*—No. I believe they are iron, with a siliceous matrix.

Marley.—Has one of those globules ever been analyzed by itself, and found to be pure iron?

Wood.—I do not know; but I believe there is no calcareous matter in those particles which there would be if it were shells.

Marley.—Unless it is some peculiar formation.

Wood.—Then the shell is gone, and the iron left.

Boyd.—The chemical part of the shell remains in the Cleveland stone.

Marley.—The magnetic stone is not in analogy with the Cleveland.

Wood.—It has changed its character from a peroxide to a protoxide.

Marley.—I acknowledge the magnetic stone is free from "pectens."

Bewick.—After hearing what has been stated by our President, I am bound to say our opinions are as much opposed as ever; and I shall endeavour to show you that the ironstone beds they have BORED THROUGH at Rosedale Abbey are not the same as the magnetic ore and top bed found by the side of the valley, that, in fact, the borings have not reached those deposits by several feet, and that, therefore, *they have not as yet proved anything more respecting them.* The strata they have bored through are quite above them, and you will find on looking at the table of the borings,

published with the July discussion, that an important member of the series, which immediately overlies the top bed is wanting. I allude to the great sandstone rock, which is seldom under 50, and sometimes met with 100 ft. thick. This rock does not appear in the borings at all.

Wood.—Yes, it does, namely :—

		Fms.	Ft.	In.	
Brown freestone ..	No. 1 bore-hole	12	5	6	with other beds of post, mixed with shale.
Brown and grey post	" 2 "	12	1	0	
Brown post	" 3 "	11	5	0	

Bewick.—That is not the sandstone I allude to. That rock is found higher in the series, and belongs to the coal measures, which your *bore-holes* have gone through; but, as I have just said, they have not yet reached the other sandstone, and cannot, therefore, have touched the top bed. In this section, Fig. 1096, you have, in my opinion, a type of the ironstone you have gone through in your borings. The seams here are thin and divided, and the shale between them is interspersed with iron nodules; and, as you admit the seams are split in the last *bore-hole*, it but serves to confirm my opinion that they are one and the same. They occupy the same geological position in the series—that is, they intervene the great sandstone rock and the coal measures in the oolitic series.

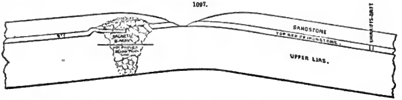
1096.

Reference :—1, 2, 3, Sandstone, shale, and coal. 4, Sandstone. 5, Upper lias. *a*, *b*, *c*, Ironstone.

Wood.—Do you purpose giving the sections for publication ?

Bewick.—Yes ; I intend leaving the whole of the sections with you for that purpose. The thickness of every stratum, in the diagram representing a cross-section of the vale of Rosedale, is taken from the table of the borings before referred to, in which I may here observe there is an error of 3 fathoms 2 ft. The total ought to be 48 fathoms 2 ft. instead of 51 fathoms 4 ft. ; and if you take from this 1 fathom 1 ft. for the grey shale they have left off in, below the ironstone, it leaves 47 fathoms 1 ft. from the top of the bore-hole to the bottom of the ironstone. I am thus particular because I have taken a line of levels, commencing at the south drift, by the side of the hill, and terminating at the *south bore-hole* ; and I find there is a difference in the height of the level, and the depth of No. 2 *bore-hole*, Fig. 1090, of 64 ft., fully corroborating what I have before stated, namely, —That the *bore-holes* have not yet reached the sandstone which overlies the top bed ; and if you will allow me to explain my sections, I think they will prove to you that the ironstone they have cut through belongs to that which we call the oolitic beds, and which are found in different localities in the Grosmont district, not so thick, it is true, neither are they magnetic ; but they are found, as I before stated, occupying the same geological position, and accompanied by the same description of strata. Section, Fig. 1096, is taken between Goathland Mill and Beckhole, near Grosmont, which, you will observe, contains the same alternating strata of sandstone, shale, coal, and ironstone, as you see in section, Fig. 1087, which is a transverse section of the vale of Rosedale, representing the strata they have bored through there. The ironstone beds *a* and *c*, in section, Fig. 1096, are, in my opinion, the same as those marked *a* and *c* in section, Fig. 1087. The bed *c* is very irregularly diffused throughout this portion of the oolitic district. It is found in the nodular form. In some places you find it of considerable thickness, and then, again, entirely wanting. Sometimes of good quality, but more frequently coarse and inferior, and gradually alternating with the sandstones. The bed *a* is more regular, but thinner, and of very good quality ; its upper portion consists of a nodular bed averaging from 3 to 6 in. ; and the lower portion a bed averaging from 12 to 18 in. in thickness. Wherever I have met with those beds, however, I have always found them so variable, both in extent and thickness,

1097.



as to afford no reasonable prospect of their paying for working. They may certainly be found different at Rosedale ; but I would just observe that I consider *boring a most fallacious mode of proving ironstone deposits in strata* such as that which these borings have gone through, you are so liable to mistake a nodule for a bed, or a portion of a bed. I shall be much surprised if you do

not find the section of your shaft, should you sink one, very different from the section of your *bore-hole*.

Wood.—Then it is a question of policy, in Bewick's view of the case, commercially considered, whether the borings should not be continued. With regard to the identity of the position in the series of the bed of ironstone ranging around the Rosedale valley, as shown in Fig. 1097, and also in Fig. 1087, it appears to be undoubtedly the top bed of Cleveland. All parties admit this. Then the question is, Is the bed of ironstone proved at the pit No. 1, Fig. 1089, and the bed corresponding therewith and proved in the bore-holes Nos. 1, 2, and 3, and therein designated by me as the top seam, the same bed of ironstone? Bewick thinks not, and that the borings have not yet reached this bed. I can, of course, only refer to the borings, driftings, and the section of pit No. 1, and I must add that there appears to me no doubt whatever on the subject; and the fact that, according to Bewick's plan, Fig. 1097, we have the top bed on both sides of the magnetic quarry, ranging as accurately as can be conceived with this bed in the borings, confirms this supposition, in my opinion. It is true that this bed is at a lower level at the south or left-hand drift than on the north side, but this is clearly the effect of the dyke shown in Fig. 1087, which throws down the strata in that direction. With regard to the supposed want of what Bewick calls the thick sandstone strata immediately above the top bed of ironstone, and shown on the section, Fig. 1096, to be 100 ft. thick, I have looked carefully over the sections given in Marley's paper, and I do not find in any one of them, except at Eston Nab, the extreme northern point of the district, any bed of sandstone approaching to that thickness, and there the section given is

	Ft.	In.
Freestone	60	0
Shivery post, patches of jet, and fire-clay	54	0
Top seam, exclusive of shale bands	1	3

At Rosedale Cliffs, between Staiths and Runswick Bay, we have

Freestone	26	0
Fire-clay	4	6
Freestone shale	5	5
Blue shale	0	10
Top seam, exclusive of shale bands	4	7

Still farther south, the sandstone at Wreck Hill is only 10 ft., with 2 ft. 6 in. of shale covering the top seam; and at Grosmont, Marley gives 25 ft. of sandstone, and another section at 58 ft. 6 in., which he says varies in thickness and quality. At Fryupdale, the thickness of sandstone is given at 55 ft., and at another place, namely, Swainby, the following is the section:—

	Ft.	In.	Ft.	In.	
Soil, &c.			3	0	
Freestone			24	0	Near the limekiln this is 100, with 9-inch ironstone balls in it.
Slaty coal	0	9			
Shale	1	0			
Sandstone	4	0			
Slaty coal	0	9			
	6	6			
Shale	5	0			
Coarse freestone	3	6			
Shale, with occasional nodules of ironstone	13	0			
Top seam			28	0	

Considering, therefore, that in the borings there is about 60 ft. of sandstone, there does not appear to me any substantial difference between the shale in those borings and in the other parts of the district to justify the supposition that the upper bed of ironstone is not the top seam. Bewick thinks the bore-holes have not reached the sandstone he describes. If so, he should like to ask Bewick what seam of ironstone that is in the district which has been bored to?

Bewick.—It is, in my opinion, as I have previously stated, the ironstone found in the oolitic series.

Wood.—Where does it occur in the other districts? Where do you find another similar deposit in Mr. Marley's sections?

Marley.—Dr. Verity gives a variety of ironstone seams. If you refer to my paper, you will find there are several ironstone seams lying over the seam, which we agree to be the top seam of Cleveland. Professor Phillips said that, with the exception of the classification of names, this section was practically correct.

Wood.—Do you think the ironstone which crops out all around the valley of Rosedale is the top seam?

Bewick.—I think so; I have no doubt about it.

Wood.—If we are agreed about the deposit of ironstone found cropping out around the valley of Rosedale, as shown in the different plans, then there can be no difficulty in tracing the sandstone overlying that bed to the sandstone first of all sunk through at the pit, Fig. 1089, and thence to the borings Nos. 1, 2, and 3; and these borings having passed through the upper bed of ironstone, below such sandstone, and then through the magnetic bed, there cannot be the least doubt of the geological position of these beds. With reference to the levels, there is no discrepancy whatever

in that respect; there is a rise in beds in the line of the drift, and in the extension of that line to the borings, and the direction of the line between the borings seems to be nearly water-level at that part. There is not, therefore, the least discrepancy on this point. I have taken the Ordnance maps as my guide as regards the levels, and have no doubt they are correct. Whatever opinion may, therefore, be arrived at with respect to the comparison of the beds proved in the borings and in the pit, with the beds at Grosmont, &c., there appears no doubt in my mind that the mass of ironstone of the quarry is a detached portion of the thick or lower bed of ironstone, and that such bed exists *in situ* for a considerable, and, of course, at present, for an unknown extent in the locality of Rosedale.

Bewick.—If our President means by pit Fig. 1089 the air-shaft sunk on the main drift, I quite agree with him that the sandstone found in that shaft is the same as that which overlies the top seam; but, I beg to say, I entirely differ from him in supposing it to be the same as that they have gone through in the borings. I am also opposed to his opinion with reference to the direction of the dip and rise of the strata. There can be no doubt, I think, but the strata on the west side of Rosedale, *and to the south of the crown*—that is, the point from whence the strata dip in contrary directions—are dipping in a south-westerly direction, as shown in my section, Fig. 1097, and still more clearly proved by the drift commenced on the south side of the magnetic dyke, and driven in a line with the south bore-hole, running nearly west, but which has been discontinued, owing to the top seam, in which the drift was commenced, dipping so much in that direction, instead of rising, as our President supposes, as, at the distance of not many yards, to be completely under water-level. With reference to the slip-dyke or fault mentioned by that gentleman, I can only state that I have never yet been able to discover any dislocation or disturbance of the strata, other than what has been occasioned by the dyke of magnetic ore in its immediate vicinity. Then, as to the extent of the magnetic ore, all I can say is, I have paid several visits to Rosedale solely for the purpose of examining the strata in that neighbourhood, the many deep ravines which abound there affording ample opportunity for doing so, but I have never been able to trace the magnetic ore beyond the vicinity of the quarry, end every visit only serves to convince me that it is a casual deposit, in the shape of a dyke or vein. A bed, however, of 560 yds. in length, and from 30 to 32 ft. thick, cannot be identified with a casual deposit; nevertheless, I think, very probably there may be a mistake in supposing you have a solid mass of ironstone 32 ft. thick. This may have occurred from the borers having cut through nodules or irregular patches of ironstone, and also from the shale in which it is found being very hard, and of the same colour as the ironstone. From these circumstances it is an easy matter to be misled by borings.

Wood.—Whatever may have been the result of investigations on the surface, I do not think I can add any further information to that already given and shown on the plans, to prove that a thick bed of ironstone of about 32 ft. exists over a space of upwards of 560 yds. in length, and 200 yds. in width, with not the least indication of any change or termination of such deposit. It would, indeed, be a most extraordinary occurrence in the annals of boring, to suppose that occasional nodules, or irregular patches of ironstone, should have produced the result recorded in these borings. The boring through the ironstone beds was performed under the immediate inspection of *Stott*, a well-known experienced borer, who kept the specimens brought up the bore-hole; and I can add, that I examined a great many of the specimens myself with a magnet, and found them magnetic. There is not the least pretence for supposing that shale could be mistaken for ironstone. Have you seen any nodular magnetic ironstone in the Grosmont district?

Bewick.—Never. You must remember (addressing the President) that you stated at the October discussion in 1857, that Professor Phillips and yourself had discovered the magnetic ore in "two localities two miles apart," namely, at Sheriffs drift and at the Quarry; and, again, in the July discussion of last year, you stated the stone in the drift south of the dyke was magnetic, but on examining it I found this not to be the case as regards both the drifts. I believe the reason why there are so many conflicting opinions with reference to the nature and extent of the magnetic ore is owing to the difficulty there is in distinguishing the ore from the top bed—that is, in separating the igneous portions from the sedimentary; for, although they are both frequently magnetic in the immediate vicinity of the dyke, there is yet a vast difference between them. The igneous portion is harder, heavier, and more compact than the sedimentary; and the former appears to have acted upon the latter whilst in a heated condition, much in the same way as a magnet acts upon a piece of common iron, imparting to it a portion of its peculiar magnetic properties. I may here be permitted to add, that whilst I believe this ore to have been subject to a heat sufficient to evolve the different gases it contained, I yet do not think the heat has been of that intensity so as *entirely* to expel it. We need not, therefore, be surprised at *traces* of carbonic acid being found in the chemical analysis of this ore. Here is a specimen of the igneous portion, which I took from the bottom of the quarry, and, after examining it, no one can doubt, I think, of its having been subjected to heat.

Wood.—There is no doubt, as stated by Mr. Bewick, that portions of the top bed in Rosedale are occasionally magnetic, and it was this property which led to the mistake, if there are mistakes, in supposing the magnetic bed to have been discovered at Sheriffs drift, and at the drift south of the magnetic quarry. The explorations at that time had not been sufficiently extended, nor have they yet been prosecuted to such an extent as to ascertain if the magnetic bed exists in those localities. Finding part of the ironstone partaking of magnetic influence led to a supposition that this bed did exist in those localities, and the subsequent explorations have not been prosecuted to an extent to ascertain the fact either one way or the other. To *Bewick.*—From what part of the quarry did you take this specimen?

Bewick.—It is from the floor of the quarry. This (showing another specimen) is a sample of the top bed which appears to have been partially burnt, and you will at once be able to detect the difference between them. These (showing other specimens) are samples of the ironstone found in the oolitic rocks, in the neighbourhood of Grosmont, some of the nodules of which are amongst

the richest of the clay or calcareous ironstones. I omitted to state that, with the exception of the first 60 ft., where the ground was so steep that I could not fix my instrument, and from which there may be some slight inaccuracies, I took my levels with a good and safe instrument, and the operation was performed in the ordinary way of back and fore sights. I find the difference between my levels and what I suppose the correct position of the top bed of ironstone, and that shown by the bore-holes, to be 64 ft.

Wood.—The question of the difference of the levels rests entirely upon the assumed inclination of the beds; a difference of level of 64 ft. in a distance of 400 yds., accords, in my opinion, with what may be supposed to be the regular inclination of the beds.

Bewick.—Yes; but in your section you connect two sandstones which have nothing to do with each other, namely, the sandstone found in the air-shaft immediately overlying the top bed, and the sandstone found in the bore-hole, between which there are several feet of *alternating strata;* and to do which you must of necessity raise your level line, and show the strata to be rising in that direction; but the drift you have driven some distance into the side of the bill, and at the same point as my line of levels, shows the strata to be *dipping in that direction.* I may mention, too, that had another bed of 32 ft. thick really been met with in the bore-hole, it must have been found along the sides of the valley, which are intersected in so many places with mountain streams, all of which have been searched by persons having a fair knowledge of the geology of the immediate neighbourhood, but without the least trace of it having been met with.

Wood.—I cannot think that there is the least doubt that the sandstone in the pit, No. 1, Fig. 1089, is the same sandstone as that proved in the borings; all the appearances on the surface, as well as the general rise and dip of the strata, prove this. Extending the line of section across the valley, it is clear there is a general rise of strata along the line of section. No doubt the strata in the drift dip towards the west, but that is no doubt influenced by the slip-dyke which crosses it. I would observe that, taking the line of section along the face of the valley in Fig. 1087, in the direction of the dotted line *a b*, and applying the inclination of the top bed of ironstone, shown Fig. 1097, to that line, and not to the curved or projecting line along the face of the bill, the position of the bed would be rising from *a* towards *b*, and it would require a slip-dyke, shown Fig. 1087, to throw the bed into its proper position along the face of the valley to the west of the magnetic quarry. On examining Fig. 1087 it will be seen that the magnetic quarry and the top bed of ironstone, as shown in Fig. 1097, project considerably to the east of the general line of the side of the valley, which, being towards the dip of the strata, shows the top bed at a lower level than if the section had been continued in a more direct line, or in the direction *a b*. Whatever conclusion, therefore, may be arrived at after all the explanations given, we have the fact of an almost horizontal bed of ironstone, and of nearly a uniform thickness, distinct in character from the ordinary beds of the district, extending over a length of 568 yds. and a width of 200 yds., which clearly proves that it is not a vein. How much greater distance it extends, must be left to future explorations to prove; but it would certainly be an extraordinary anomaly in geology for such a thickness of strata to disappear altogether in a short distance. If it extends across the valley, as shown in *Bewick's* plan, Fig. 1096, then there is no reason to suppose that it may not extend to the same distance to the north; and if, according to Bewick, the borings have not yet reached to the top bed of ironstone, then the deposit of ironstone, in the valley of Rosedale, is richer in ore than either Professor Phillips or myself has set forth. The correct extent must, however, be left to future explorers to discover. Enough has been proved to show a most extraordinary deposit of a very peculiar and rich ironstone, and well worth further investigation.

Bewick.—There is a section of the cross drift, shown in Fig. 1089, driven at right angles from the main drift to prove the breadth of the dyke, and which, at the distance of 16 yds., cuts the shale, and apparently touches the top seam at the same time. At the distance of 6 yds. the stone in this drift ceases to be magnetic. It is, therefore, incomprehensible to me how it can again become so at the distance of 200 yds. from this point. Of course, you have a right to infer from the information that reached you that such is the case. Still I would strongly recommend that the borings should be continued to prove whether the sandstone be below you or not, to ascertain which could not fail to give great satisfaction to all concerned; the cost would not be great, as the bottom of your borings must be near the top of that rock.

Wood.—The cross drift was not sufficiently extended to the west to prove the dyke, but, as there was a considerable rise of the strata in that direction, no doubt such an inclination has been occasioned by the proximity of the dyke, shown on the plans, Figs. 1087, 1088. All the facts show that the slip-dyke has been a dislocation subsequent to the formation and consolidation of the various beds affected by it; and consequently such dyke could not, we can scarcely conceive, have any influence on the character of the ironstone bed itself, especially as it is not contended, I believe, that such dykes are either of a basaltic or mineral character, there being no appearance, in my judgment, to justify such a conclusion.

Tubing Bore-holes.—P. S. Reid being consulted as to the chance of finding coal in the Cleveland district, at Kirklevington, near Yarm, and finally he was requested to superintend a boring then pursued to the depth of 582½ ft., but which, owing to circumstances which were difficult to determine, had become very expensive, and made slow progress.

The 582½ ft. had been done entirely by manual labour; but Reid recommended the erection of a horse-gin, in which the power was applied to a 40-in. drum placed upon a vertical axle, the arms of which admitted of applying two horses, and men at pleasure, the power gained being in the proportion of one to ten at the starting-point for the horses.

Upon the upright drum a double-ended chain was attached, which worked over sheer-legs erected immediately over the hole, so as to attain an offtake for the rods of 10 fathoms, and so as that, in the act of raising or lowering, there might always be one end of the chain in the bottom, ready to be attached, and expedite the work as much as possible.

These arrangements being made, it was soon found that there was a defect in the tubing which was inserted to the depth of 109 ft., and the defect was so serious, in permitting the sand to descend and be again brought up with the boring-tools, as to render it very difficult to tell in what strata they really were; this increased to such an extent as to cause the silting up of the hole in a single night to the extent of 30 fathoms, and occupied nearly a fortnight in clearing the hole out again.

On carefully examining into this defect, it appeared that the water rose in the hole to the depth of A, Fig. 1098, 74 ft. from the surface: and that at this point it was about level with the high-water mark on the Tees, about two miles distant, which it was no doubt connected with, by means of permeable gravel beds, extending from the arenaceous strata at B, Fig. 1098.

On commencing to bore, the motion of the rods in the hole caused the vibration of the water between A and C at the bottom of the tubing, and so disturbed the quiescent sand as to cause it to run down through the faults in the lower end of the tubing at the latter point.

This tubing was made of galvanized iron plates, riveted together and soldered so as to attempt to make it a water-tight casing; at the top of the hole it was in three concentric circles, which had been screwed and forced down successively until an obstacle was met with at each different place shown by the letters D, E, C. So soon as the outer circle reached the depth of D, all hope appears to have vanished, from those who bored the earlier part of the work, of getting the tube farther; a second tube was, therefore, inserted, which seems to have advanced as far as the point marked E, where it, in its turn, was abandoned; and a third one advanced until it rested in the strata at C, which is, no doubt, the lower part of the lias freestone of a blue nature, as found on the rocks at Seaton Carew, and in the bed of the Leven, near Hutton Rudby. The diameter of the first tubing was 3¾ in. external and 3½ in. internal; the second tube was 3¼ in. external and 3 in. internal diameter; and the third tube was 2⅞ in. external and 2½ in. internal diameter.

Such being the account gathered from the workmen who superintended the earlier part of the boring, it became necessary to decide upon the best course to remedy the evil. At first sight it would have appeared easy enough to have caught the lower end of the tubes by means of a fish-head properly contrived, and thus to have lifted them out of the hole, and replaced them with a perfect tube, such as a gas-tube, with faucet screw-joints: but, on attempting this, it soon became evident that, however perfect the description of tubing which might have been adopted, it would be a work of the greatest difficulty to extract when once it was regularly fixed and jammed into its place by the tenacious clayey strata surrounding it; and that the difficulty of extracting, in the present case, was even enhanced by the inferior quality and make of the tubing: in short, that, unless by crumpling it up in such a manner as to destroy the hole, it was impossible to extract this tubing by main force.

There was, therefore, no other choice left, but to attempt cutting it out, inch by inch; though before doing so, I may add, says Reid, that we did attempt main force, to the extent of upwards of 30 tons, applied to the bottom of the tubing, in which the only success we attained was, the losing of several pieces of steel down the hole, which we were compelled to fish up with a powerful magnet.

After much mature consideration and contrivance, it was determined to order such a perfect tubing as would at the same time present as little obstacle as possible to the clay to be passed through on the outside, as well as surround the largest of the three tubes then in the hole, and present no obstacle to their being withdrawn through its interior.

These tubes were made 12 ft. in length, flush outside and in, the lower portion being steeled for 6 in. from the bottom end, so as to cut its way and follow down the space, and cover that exposed by the old tubes when cut and drawn, as shown in Fig. 1099.

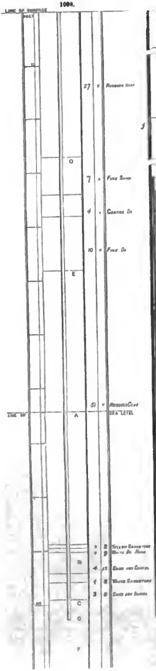
In order to commence operations, and avoid too much clay going down to the bottom of the hole, a straw-plug was firmly fixed in the lias portion of the hole at F, Fig. 1098. The lower portion of the new tubes was then screwed on to the top of the old ones by means of powerful clamps, attached to the exterior in such a manner as to avoid injuring the surface; and so soon as it was evident that they could be screwed no farther, the knife or cutter, Figs. 1099 to 1101, was introduced inside the old tubing. Some force, it will be evident, was needed to get this knife down into the tubing, but the spring *a* giving so as to accommodate itself to the hole, permitted its descent to the distance required; this being effected, it was turned round so that the steel cutter, shown at *b*, being forced against the sides of the tube, cut it through in the course of ten minutes or a quarter of an hour's turning. See section at *b*, *c*, Fig. 1101.

The old tubes being three-ply, three of these knives or cutters were required to cut out the three tubes, the inner one being detached first, and then the two exterior ones; and so soon as these latter were cut out as far as they had been forced into the clay, the work became simplified into following down the interior tubing by the new tubes, as shown by the dotted lines from *d* to *e*, until we arrived at the lower end, where it was evident that the old inner tube had been so damaged or torn, either by the putting in or hammering it down, as to leave a vent or fissure for the sand to descend, and thus spoil the whole of the work for all future success in the boring, to say nothing of the very great cost of lifting the sand out, and subsequent most arduous labour to put the hole right.

We (says Reid) finally recommenced the boring after about a month's labour in taking out the old tubings, leaving the new ones firmly bedded into the lias formation at G, Fig. 1098, 112 ft. from the surface, and subsequently bored to a depth of 710 ft. in the new red sandstone formation, proceeding at the rate of about 3 ft. in the 12 hours, and leaving the hole so as, if requisite, it may be widened out to 4 in. diameter; and, possibly, should more sand be met with on reaching the magnesian limestone, or sands connected with it, it may again be retubed and the work continued to such depth as may be desirable.

Reid observed, in his paper published in the 'Transactions of the North of England I. M. E.,' "To the care of G. B. Lloyd in the manufacture I attribute a good deal of my success in renewing these tubes. At the same time, the experience so gained in their construction convinces me that if adopted in many places where air-holes are required in mines, and which will not justify the

1098.



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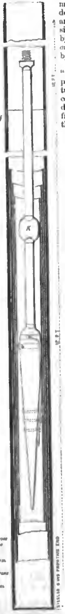

cost of sinking a pit on a large scale by manual labour, good well-made tubes of this description might, even up to 18 in. diameter, answer as a convenient tubing for air-shaft sides; and the interior could be extracted by boring-tools, similarly to those adopted in *artesian wells* and mines on the Continent, by Kind and Dégousée.

"I am further convinced," remarks Reid, "that in the artesian wells, especially in passing through objectionable springs, the tubes would answer admirably, and that they could, by powerful clamps, be readily forced down, so as to secure a large volume of water from the lower strata, and effectually prevent the injurious mixture of inferior supplies.

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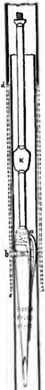

"Fig. 1098 shows the geological position of the upper portion of the bore-hole, and the depth to which the imperfect tubing was inserted; it also shows the tidal range, which we were ultimately able to take advantage of, by sinking so as to get 4 fathoms more offtake, and expedite the work; the water

still rising only to A, and flowing always from that point when passed down the hole. Fig. 1099 shows the action of the knife and spring-cutter, when forced down into the tubing, ready to commence cutting. It also shows the lower end of the new tubing enclosing the others at the commencement of the work; the junction of the tubes, by means of the half-lap screw, being shown at *j*. Fig. 1100 shows a front view, with knife or cutter *b*. Fig. 1101 shows the action of the spring and cutter when the requisite length is cut through and ready for lifting; the position of the tube being maintained perpendicular, or nearly so, by the ball or thickening on the rods at K, and the lower end of the tube being supported by the projecting steel cutter at *b*, the dotted lines from *d* to *e* showing the position of the new steel-ended tube when screwed down ready for another operation. In boring deeper after the tubes were removed, three wooden blocks were used round the rods in the new tube to keep them plumb.

"In examining the nature of the strata thus passed through, as described, it will be evident that, to ensure success, the tubing, of whatever it is made, should be as truly cylindrical as possible, straight, and flush surface, both outside and in. It will also be evident that in thus joining pieces of tubing together in this manner, the thickness ought to have a due proportion to the work required, and the force likely to be used in screwing them down; and also that the only correct way of getting such tubes effectively into the ground is by screwing and not hammering, as in the case of pile-driving, or similarly to forcing a nail in. The author has seen this attempted on several occasions, but invariably with failure to the success of the work, and is convinced that no successful practical borer will adopt such measures.

"In some cases we had to widen out holes below the sharp edge of tubing, so as to permit its descent. This is an operation requiring great care and attention." P. S. Reid, in concluding, observed, "That no branch of mine-engineering is qualified to bring out more thoroughly the abilities of a young engineer than a perfect knowledge of the science of boring, requiring, as it does, the best mechanical skill, as well as the best knowledge of assaying rocks by chemical analysis. He is aware of more than one deep boring in important districts, which were finished many years ago, and cost large sums of money, but which, in the then knowledge of chemistry, were not critically examined, and hence, so far as their results are concerned, are utterly useless; the fact being that, beyond the colour of the material bored through, it is unknown whether it was a limestone, or what it was, to this day."

Rock-boring Machinery.—In driving a tunnel or quarrying in hard rock, the only method whereby the rock can be worked is by blasting; and the Rock-boring Machine, which we will presently describe, was constructed by George Low for the purpose of boring the blasting holes, with a view to facilitate and expedite the work by superseding the very slow and laborious mode of performing this operation by hand. The machine is driven by compressed air, and works a boring tool or jumper for boring the holes; and the boring-tool works in a direct line, with a self-acting reciprocating motion at a very high velocity, and is continuously turned round during its working, being made to rotate slightly between each blow.

The boring-tool is fixed direct upon the end of the piston-rod of a working cylinder; and this working cylinder moves within another exterior cylinder, in which it is made to rotate for the purpose of giving the rotating motion to the tool. The working cylinder has also a longitudinal forward motion within the exterior cylinder for giving the advancing feed to the tool, the working cylinder being propelled forwards by the compressed air that works the tool, thereby dispensing with the necessity for employing propelling gear, which is liable to break or get out of order, and is subject to rapid wear. The exterior cylinder is carried by a spherical trunnion in a movable radial arm or jib mounted on a travelling carriage, which gives the means of adjusting the boring-tool to any desired direction and position, so that the holes may be bored in the most suitable directions, according to the strata of the rock, for the blasting to take the best effect in breaking up the rock.

This rock-boring machine, which is the invention of G. Low, is shown in Figs. 1102 to 1112. Figs. 1102 to 1106 are sectional plans and longitudinal sections, showing the boring-tool and working cylinder in different positions during the working of the machine; and Figs. 1107 to 1112 are transverse sections at successive points.

The machine is only 4 ft. 6 in. total length, being made as short as possible in order that it may be moved in any direction in the tunnel, so as to enable it to be set to bore at any angle and in any position and direction that may be desired. The working cylinder A, Fig. 1104, constructed of brass, is placed inside an exterior cylinder B of cast iron, which is fitted with a spherical trunnion C to support it in the radial jib or arm of the travelling carriage, as shown in Figs. 1122, 1123. The inner cylinder A is free to move longitudinally within the exterior cylinder from end to end as it advances during the process of boring, as shown in Figs. 1104 and 1106; and it is also free to rotate within the outer cylinder, for giving the rotating motion to the boring-tool D. The back end of the working cylinder A is packed with a cupped leather, shown black in Fig. 1106, so as to be air-tight when moving within the exterior cylinder B. The front end of the working cylinder A fits into a wrought-iron cross-head E, in which it is free to revolve; this cross-head is bored out on each side to slide upon the two screwed guide-bars F, which are bolted to the exterior cylinder B, Figs. 1106, 1110, and 1111, and are carried forwards to the end bearing G of the machine. The guide-bars F have a double thread of 1½-in. pitch chased upon them from end to end, but the thread is planed off on the inner side of each screw down to the body of the guide-bar, for the purpose of obtaining greater compactness in the construction of the machine, as seen in the transverse sections, Figs. 1110 to 1112.

At the back end of the working cylinder A is the air-valve N, Figs. 1106 to 1108, which is a circular disc valve with six inlet-ports and six exhaust-ports, as seen in Figs. 1107, 1108. This valve is turned by a double spiral cam O, which is carried forwards into the end of the piston and piston-rod K, and is acted upon by the four rollers P P, Figs. 1106, 1109, bearing on both sides of the spiral wings of the cam. The spiral wings are so sloped that as the piston moves backwards

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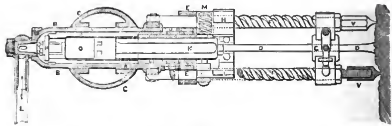

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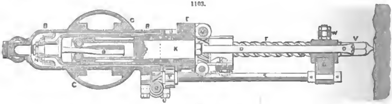

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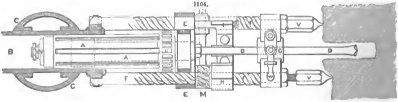

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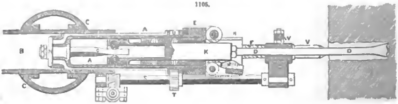

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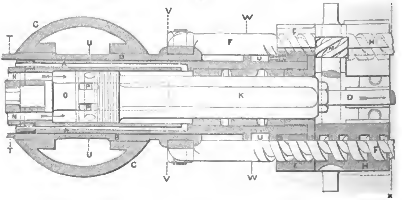

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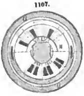

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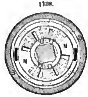

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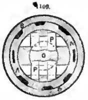

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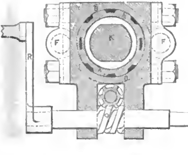

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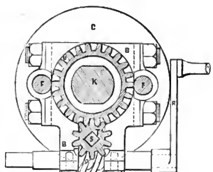

and forwards the cam is gently turned or twisted, carrying with it the air-valve N fixed upon the spindle of the cam. The slopes of the cam are so arranged that the valve N opens the inlet-ports for admitting the compressed air to act upon the large area of the piston, in order to make the forward stroke of the tool; and the valve is then turned so as to allow the air to exhaust again after the piston has struck the blow. The return stroke of the piston is produced by a constant pressure of the compressed air upon the small annular area of the front of the piston, the pressure for this purpose being maintained through the two ports shown in Figs. 1106 to 1110, which are always open. The exhaust air is discharged at the front end of the exterior cylinder B, being carried along grooves in the circumference of the working cylinder A, as seen in the plan, Fig. 1104, and the transverse sections, Figs. 1107 to 1110.

The boring-tool is caused to rotate by rotating the working cylinder A, the piston being prevented from turning in the cylinder by means of two flats planed on opposite sides of the piston-rod K, which fit into corresponding flats in the stuffing-box of the cylinder, as seen in Figs. 1106, 1110, and 1115. The rotating of the working cylinder A, with the piston and boring-tool, is effected by hand by the worm Q, Fig. 1110, which is turned by the handle R, Figs. 1110, 1111, and gears into a worm-wheel fixed on the square shaft S. The brass pinion T, Figs. 1103, 1105, and 1111, slides upon the shaft S, and gears into the teeth U round the circumference of the working cylinder A, Figs. 1104, 1111; so that by turning the handle R the working cylinder is caused to rotate; and as the cylinder advances at each turn of the nuts H, the pinion T slides forwards with it along the square shaft S, as seen in Fig. 1105. In an earlier construction of the boring machine, having a pair of cylindrical trunnions instead of the present spherical bearing C, a self-acting rotating motion was obtained from the spiral cam O that works the disc air-valve N, by prolonging the spindle of the cam through the back end of the exterior cylinder B; and a couple of pawls on the end of the spindle worked into a ratchet-wheel on the end of the square shaft S, which was also prolonged backwards for the purpose in the absence of the spherical bearing C. In practice, however, it has been found preferable to rotate the working cylinder by hand, by means of the handle R, as above described, because the very rapid reciprocation was very severe upon the self-acting rotating motion, making it liable to derangement; and the hand arrangement, besides having the advantage of simplicity, avoids the necessity of prolonging the shaft S backwards, and thus allows of adopting the spherical trunnion C, which gives increased facility for turning the machine into any position desired for boring the holes.

The cross-head E slides forwards along the two screwed bars F as the working cylinder A is advanced inside the exterior cylinder B during the process of boring; and in front of the cross-head the nuts H are fitted on the screwed bars F, against which the cross-head and with it the working cylinder are pressed by the pressure of the compressed air behind the working cylinder A. The nuts H are held from turning, and thereby prevented from going forwards, by four projecting stops upon their circumference, Fig. 1112, which are caught by the catches I below; these catches are kept pressed up by springs against the under-side of the nuts; and between the two

catches is placed a tappet J, so curved that it may be struck by the end of the piston-rod when the latter has reached the outer extremity of its stroke, as shown in Fig. 1105.

The mode of action of this advance motion is as follows:—The compressed air is admitted by the flexible pipe L into the exterior cylinder B behind the back end of the working cylinder A, which is thus kept pressed outwards against the cross-head E, while the cross-head is kept in its place and prevented from going forwards by the nuts H, and these are prevented from turning by the catches I. But when the boring-tool D has advanced ⅜ in., the distance due to one quarter turn of the nuts H, the outer end of the piston-rod K, which is allowed a range of ⅜ in. variation in the length of its stroke, strikes against the tappet J, as shown in Fig. 1105, and depresses it sufficiently to make the catches I release the projections on the nuts H; the forward pressure of the working cylinder and cross-head against the nuts then causes them to slip past the catches and advance one quarter turn, thereby moving forwards ⅜ in. upon the screwed bars F, when the next projections on the circumference of the nuts are caught by the catches I. This process is repeated for every ⅜ in. bored by the tool, until the nuts reach the front end of the screwed bars F.

By this arrangement the boring-tool is allowed to advance at whatever rate it may be cutting in the rock. When the rock is comparatively easy to bore and the tool is cutting rapidly, the projections on the nuts slip past the catches from one to another rapidly, and consequently allow each successive ⅜-in. advance to occur more quickly; whilst when the rock is harder and the tool is cutting slowly, there is so much longer an interval between each release of the catches, and the advance of the nuts is less frequent, thus admitting of a greater number of strokes being made by the boring-tool for each ⅜-in. length of hole bored.

For winding back the working cylinder A by hand, when required for the purpose of changing the boring-tool, the two worms M M, Fig. 1112, turned by a hand-wheel, are geared into the nuts H, as shown in Figs. 1102 to 1106. The friction of the worms also acts as a break to prevent the nuts from turning too suddenly, as it causes them to move gently when the projections on the nuts are released by the catches I at each ⅜-in. advance of the boring-tool.

As the working cylinder A and cross-head E only press loosely forwards against the nuts H, neither the nuts nor the screwed bars F receive the slightest portion of the concussion from the blows of the tool; but the shock of each blow is conveyed direct to the air-cushion behind the working cylinder A, in the back end of the exterior cylinder B. This effectually prevents crystallization of the portions that are exposed to the direct concussion of the blow, and prevents any loosening of the several parts of the machine; it also relieves the carriage-frame from the full shock of the blow, and steadies the boring cylinder.

At the outer end of the two guide-bars F are two screwed caps V V with steel points, Figs. 1102, 1104, for the purpose of steadying the end of the machine against the rock. The outer end of the boring-tool D is steadied in the front bearing G, across the end of the two guide-bars F, in order to compel the tool to bore straight when it meets with extra hard rock or quartz veins inclined to the direction of the hole; and by turning the handle W, the top bearing or step can be readily lifted out when the boring-tool requires taking out for changing. During the working of the tool a jet of water is kept constantly playing into the hole; and this, aided by the reciprocation of the tool, effectually clears out all the loose material as fast as it is detached by the tool, without ever requiring the tool to be withdrawn, as in hand-labour, for the purpose of clearing out the hole. In one of these boring machines, worked in the Roundwood Tunnel of the Dublin Corporation Water-works, the water was obtained from the top of the tunnel shaft, being a

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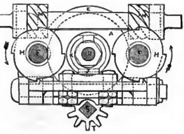

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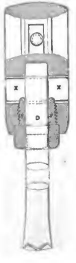
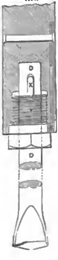


1114.



1115.

1116.

1117.

1118.

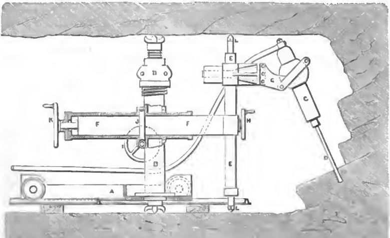
1119.

portion of that raised by the pumping engine which drained the tunnel, and the jet was thrown into the bore-hole under a pressure of about 80 lbs. per sq. in.

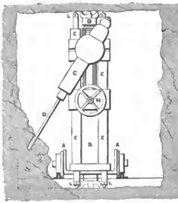
The mode of fixing the boring-tool D in the piston-rod K is shown in Figs. 1113 to 1115. The fixing of the tool is a very important point in the working of the machine, in order to ensure a thoroughly secure fixing and at the same time the means of readily and quickly changing the tool. The tool D is dropped into a socket in the end of the piston-rod K, and the parallel cotter X being then passed through is fixed by the screwed gland Y, which presses the tool home to the bottom of the socket, and secures the cotter endways by entering into the two notches in the front edge. The gland Y is prevented from turning back by a ratchet and spring Z; and for releasing the tool the spring is held back by a stud while the gland is unscrewed.

Several different forms of boring-tools have been tried with the machine, but the results of experience have led to the adoption of the two forms only that are shown in Figs. 1113 to 1119. The rose-tool, Figs. 1113, 1117, having two chisel-edges at right angles to one another, is found the best form for commencing the hole and boring the first 9 or 10 in. length. The shape of this tool, in conjunction with the continuous rotary motion given to it between each stroke, prevents

1120.



1121.



it from being led away sideways when it meets with a vein of quartz harder than the rest of the rock and lying much inclined to the direction of the hole. The second tool, Figs. 1116, 1118, used for completing the hole, is a chisel formed with the cutting-edge in three bevels a little inclined to one another in both directions. The chisel shown in Figs. 1114, 1119, was found the best for boring straight, but it could not be made to stand well, and was consequently abandoned. A hollow tool has also been tried, into which was inserted a water-jet; and the exhaust air from the cylinder was also turned into it, which blew the water out from the point of the tool into the hole with considerable force. This was found a most excellent plan for keeping the hole clean; but in consequence of its complication and the liability of the jet-orifice to become choked up with deposit from the water employed, it was abandoned, and the separate water-jet already described was substituted.

The frame and carriage for this boring machine are shown in Figs. 1120, 1121. The traversing carriage A is made very low, in order to allow of readily removing the *débris* from blasting; and upon it is mounted the upright pillar B, capable of swivelling round upon the carriage and having means for clamping it securely between the top and the bottom of the tunnel. The working cylinder C with the boring-tool D is carried by the transverse frame or rest E upon the

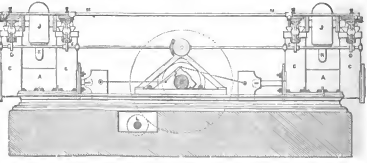
extremity of the horizontal jib F projecting from the centre pillar B. The arm G carrying the boring cylinder C can be traversed into any position in the frame E by means of a screw-motion worked by the hand-wheel H; while the frame E can itself be turned round upon the axis of the horizontal jib F by the hand-wheel I working the worm-wheel J, and the jib F can be lengthened or shortened by the hand-wheel K. By this means the boring cylinder C can be adjusted to any part of the face of the tunnel; and the spherical trunnion by which the boring cylinder is carried in the arm G allows of its being placed to bore in any position and direction. These several adjusting movements enable the tool to bore the holes in the exact line the miners may wish to place the shot, as the boring cylinder can work either upwards, downwards, sideways, or at any inclination; and all the movements are at all times central and within easy reach of the attendant, whatever may be the direction or position of working.

The transverse frame or rest E is provided at each end with a pair of projecting steel points L L, which can be lengthened or shortened so as to clamp the rest securely against the rock, thereby relieving the horizontal jib F and the pillar B from the shocks produced by the blows of the boring-tool. The steel points L L are attached to pistons inside the columns of the rest E; and, by admitting the compressed air between the pistons, the points are caused to strike out against the sides of the tunnel, and are then secured by self-locking catches. It is generally found sufficient, however, simply to wedge the hind wheels of the carriage in order to render the whole perfectly steady, without any necessity for clamping the carriage and rest against the rock.

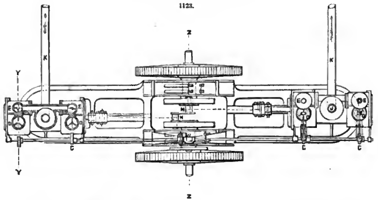
The compressed air for working the boring machine is supplied by an Air-compressing Engine at the top of the shaft, driven by a small portable steam-engine. The air-compressing engine is shown in Figs. 1122 to 1126, and consists of two horizontal compressing cylinders A A, Fig. 1122, fitted with air-tight pistons packed with brass rings or cupped leathers, Fig. 1124. On each end of the cylinder A are upright chambers C C, and on the top of each chamber are a pair of inlet and delivery air-valves, so that there are two inlet-valves D D and two delivery-valves E E to each compressing cylinder; these valves are circular, and fit air-tight upon conical faces, as seen in Figs. 1124, 1125. The four inlet-valves D D are each suspended from a lever F, and in the original construction there was simply a weight on the outer end of the lever to cause the valve to shut when the piston B had drawn in sufficient air to fill the chamber C; it was found, however, that the valves did not work very steadily with the levers and weights, and they also shut before the piston reached the end of the stroke, so that part of the stroke was wasted in uselessly expanding the air in the chamber C. A cam G, Fig. 1125, worked from the crank-shaft H, was therefore added to each of the valve-levers F; and the cam opens the inlet-valve at the commencement of each forward or suction stroke of the piston, and keeps it open till the commencement of the return or compressing stroke, when the valve is shut suddenly by the weight; and this arrangement has proved quite satisfactory. The delivery-valves E E are shut by the back-pressure, as soon as the compressed air is all forced out of the chambers C; they deliver the air into the air-vessels J, which are for the purpose of equalizing the pressure of the air under the varying pressure of the stroke. A pipe K from each of the two air-vessels conveys the compressed air to a large wrought-iron receiver, from which it is supplied for working the boring machine.

The two air-compressing cylinders A A, Figs. 1122, 1124, are each 14 in. diameter with 18 in. length of stroke, and are placed at each end of a cast-iron bed-plate; the pistons are worked by connecting-rods from the double cranks H at right angles to each other, which receive motion from the countershaft L driven by the steam-engine. By employing two cylinders of half area each for compressing the air, worked by cranks at right angles to each other, instead of a single larger cylinder, an advantage is gained in delivering the compressed air to the receiver more uniformly, and also the strain on the working parts is more evenly divided. The cylinders A are filled with water, which rises at each stroke to the top of the upright chambers C C, and the surplus water is forced through the delivery-valves E, the object being to fill up every space with water at the end of the stroke, and so ensure every particle of air being forced through the delivery-valves. To allow for leakage and waste of water, a supply is kept constantly flowing into the inlet-valves D from the small pipe M, regulated by a tap; and the water forced through the delivery-valves at each stroke keeps the air-vessels J J constantly filled with water up to the mouth of the pipe K, so that the compressed air is kept quite cool. The surplus water passing into the pipe K slowly accumulates in the large air-receiver, out of which it is discharged occasionally.

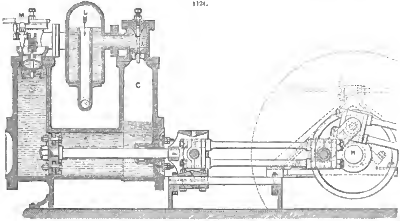
1122.



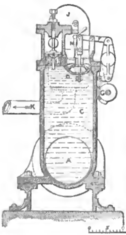
1123.



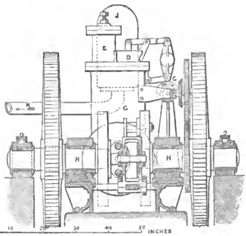
1124.



1125.



1126.



The crank-shaft H is driven at 22 revolutions a minute, and at each stroke the piston draws in the air through the inlet-valve at one end of the cylinder, and compresses the air to six atmospheres, or 90 lbs. the sq. in., at the other end of the cylinder, discharging the compressed air through the delivery-valve to the receiver. The minimum pressure maintained in the air-receiver is 75 lbs. the sq. in., and the maximum 125 lbs., the average being about 85 lbs. the sq. in. From the receiver the compressed air is conveyed, by cast-iron pipes with india-rubber joints, up to within 50 ft. of the boring machine. It is then conveyed to the machine through an india-rubber pipe made with six-ply canvas, and about 100 ft. long, which allows the boring machine to be advanced or drawn back without undoing a single joint.

This boring machine, of which a longitudinal and transverse section are shown in Figs. 1120, 1121, was employed in the construction of the Roundwood Tunnel for the Dublin Corporation Water-works, where it bored the holes for blasting at one of the working faces. The tunnel is rectangular, 5 ft. wide and 6 ft. high, and is carried through Cambrian rock of a remarkably hard and difficult character, interspersed with quartz veins. Six shot holes of 20 in. depth were usually fired at each blast, and these six holes of 1¾ in. diameter were all bored by the machine in about 3½ hours; two chisels were used for each hole, which required fresh grinding before being again used. With hand-work, however, each of the same holes takes 2½ to 3 hours for drilling, and requires usually about fifteen fresh tools before it can be completed. The practical value of this remarkable saving of time that is effected by the use of the machine is specially experienced in such work as tunnelling or other rock-blasting, where saving of time is of such great importance both in expediting and economizing the work. The average rate at which the very hard rock was bored by the machine at the Roundwood Tunnel was about 1 in. a minute; and it has been found as the result of experience with the machine that it bores quicker and keeps the edge on the tool better by striking with less force of blow but with greater rapidity. The number of blows has been increased from 250 to 500 or 600 blows a minute, and the result is that one hole is now bored with two tools without re-sharpening, instead of using five or six tools, as formerly; and with one tool a hole of 26 in. depth was bored in the Dalkey granite without re-sharpening.

The following are the results of working in the Dalkey granite :—

1st hole,	24½	inches	deep,	in 11	minutes	10	seconds.
2nd	,,	19½	,,	,,	14	,,	..	,,
3rd	,,	9	,,	,,	5	,,	55	,,
4th	,,	4½	,,	,,	2	,,	10	,,
5th	,,	9	,,	,,	7	,,	35	,,
6th	,,	9	,,	,,	5	,,	25	,,

The following are the results of working in the remarkably hard rock of the tunnel at Roundwood, Wicklow :—

1st hole ..	8½	inches	depth,	in 3½	minutes.
	6	,,	,,	8	,,
	9	,,	,,	3	,,
Total .	23½	,,	,,	14½	,,
2nd hole ..	12	,,	,,	8	,,
	9	,,	,,	4	,,
Total ..	21	,,	,,	12	,,
3rd hole ..	6	,,	,,	5	,,
	9	,,	,,	10	,,
Total ..	15	,,	,,	15	,,
4th hole ..	10	inches	depth,	in 6	minutes.
	9	,,	,,	3	,,
Total ..	19	,,	,,	9	,,
5th hole ..	10½	,,	,,	4	,,
	8	,,	,,	4½	,,
Total ..	18½	,,	,,	8½	,,
6th hole ..	14	,,	,,	10	,,

The average at which the machine continued to bore was, for the first portion of the hole, 10 and 11 in. depth in 4½ to 8 minutes; and for the second portion, 9 and 9½ in. depth in 3 to 3½ minutes.

The following special points of advantage have been experienced in this boring machine; and these may be considered as essential conditions to be fulfilled in a good machine for the purpose of boring in hard descriptions of rock, and for standing satisfactorily the special wear and tear to which such machines are necessarily subjected.

The boring part of the machine with the tool is made very short, so as to allow it to work in any direction and position in the tunnel, in order that the blast of the hole bored may displace the largest amount of rock. The carriage-frame carrying the working cylinder is also very compact, occupying little space, and allowing the cylinder to be quickly adjusted into any desired position.

The reciprocating parts are very few in number, and are in the direct line of the blow; these are only the piston and rod in one piece of steel, and the tool secured in the piston-rod so as to allow no play. Moreover, in order to prevent crystallization of the parts exposed to the direct concussion, a cushion of air is provided at the back of the working cylinder, which also relieves the carriage-frame from the shocks of the blows. Also, the tool being made to reciprocate with the piston, the hole is more easily kept free from the *débris* than when the tool is stationary and receives blows from a detached piston, as in other descriptions of boring machines; and the strong water-jet playing into the hole is found to keep it quite clear during the process of boring.

The advance of the tool is self-acting, and exactly at the same rate that the tool is cutting, however variable may be the nature of the rock; and whether the tool is cutting at the rate of

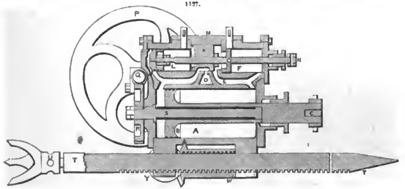
3 in. a minute in one part of the hole, or only 1 in. a minute in another part, the advance given to the tool is exactly at the same rate that the boring progresses in each case; so that there is no risk of the piston at any time working beyond its proper range of stroke, and striking the cylinder-cover. The advance motion for the tool is obtained from the pressure that drives the piston, without the use of propelling gear, the absence of which greatly increases the durability of the machine. The turning motion for the tool also, being connected to the stationary outer cylinder, is freed from the source of derangement that would arise from the rapidity of the blows of the tool if the turning motion were connected to the reciprocating part. The motion for working the valve is gradual and easy in its action, so that a very rapid action is obtained without any destructive shocks. The outer end of the tool is guided in a bearing, to prevent it from working to one side, and getting jammed when meeting with an oblique vein of harder material.

The machine is arranged so that it can be brought to work again immediately after a set of holes have been blasted and before the *débris* is removed, which can be done whilst the machine is at work, the material being carried or thrown through the clear space left by the carriage-frame; and a jet of air being left open near the face at the time of explosion soon dilutes and clears off the gases resulting from the explosion of the powder. This saves much of the loss of time which occurs with other machines in removing the *débris* before the machine can be set to work again. The compressed air, on being discharged from the boring cylinder, also serves effectively to ventilate the workings, and supplies fresh air to the miners.

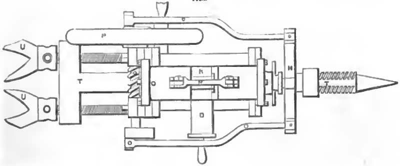
Bergstrœm's Boring Machine.—This boring machine, Figs. 1127 to 1132, which is now being used at the Perseberg mines, near the town of Philipstad, in Sweden, is a modification of that constructed by Schumann, of Freiberg.

The machine consists of a cast-iron cylinder A, Fig. 1127, 4½ in. in diameter, in which the piston B, and at the same time the borer fixed in the socket C, is moved by compressed air. The length of the stroke is 7 in. The compressed air enters by a pipe at D, and then passes through one of the ports E into the cylinder, and moves the piston backwards and forwards. F and F are two single-acting cylinders, in which the pistons O L, and their common piston-rod, are moved by air. K is the slide-valve, which is pushed backwards and forwards by bosses on the piston-rod, in order to make the air act sometimes on one side of the piston and sometimes on the other. By means of the nuts at L, the position of the slide-valve on the valve-face is determined, and con-

1127.



1128.

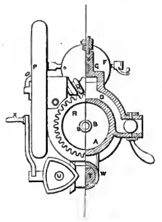


sequently at the same time the entry of the air. M is a guide for the slide-valve. On the valve-rod the cross-head N is keyed, which, by means of two connecting-rods o, sets in motion the fly-wheel P, its axle, and the worm Q, which has been formed on it. The screw takes into the worm-wheel R, which thus causes the spindle S to rotate. The spindle S has on each side a groove, in which feathers, dovetailed into the hollow piston-rod C, can readily move, and thus when the spindle turns it causes the rotation of the piston and consequently also of the borer.

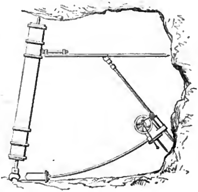
The machine hangs from, or may be supported by, a bar T having a thread cut on it. In order to prevent the machine from turning on the bar T, the thread is cut away, as shown on the cross-section and plan. By means of the screws U and U, the rod is firmly forced against the rock. The advance of the machine is effected by hand, by working a winch-handle X, which actuates a mitre-wheel Y, which gears into another mitre-wheel on the nut W. This nut W is held between two lugs cast on the cylinder, and therefore as the nut is caused to rotate the machine advances or retires. The machine gives 200 to 300 and even 350 blows a minute, and the borer makes one entire turn for 22 blows.

Strut.—In order to furnish a point of support for the screws U, a wooden strut, Fig. 1130, provided with an iron at its upper end, and at its lower with an adjustable screw and tripod, is firmly fixed across the level.

1129.



1130.



It will now be readily understood that the machine can be fixed in any position, and consequently holes can be bored in all directions. It takes two men to put up the machine, and one to attend to it. The other man can be boring by hand in the meantime.

Air-compressor.—At the Perseberg mines the machine is worked by compressed air. The air-compressor, Figs. 1131, 1132, was designed by Professor Angström. It consists of two vertical iron barrels, 15½ in. in diameter and about 8 ft. high, communicating with one another at the bottom by a chamber.

The upper end of each barrel is provided with a valve-box having two valves, one opening inwards, for the admission of air, and the other outwards into the delivery-box, for the eduction of air. In one barrel a piston is made to work up and down, and in order to deliver every particle of air at each stroke, and to keep the barrels cool, a quantity of water is placed inside the pump, which at each stroke entirely fills up the valve-box, and thus expels the whole of the air from the pump. The other barrel has no piston working in it, but is also filled with water, which is caused to rise and fall as the piston goes down and up. This water also forces out all the air from the barrel and valve-box at each stroke. The piston-rod is connected to the main rod of the pumping engine, and is provided with a cross-head, from which a weight is suspended by rods. The stroke is 7 ft. Four strokes a minute furnish enough air for one boring machine. The air must be compressed to 15 lbs. or 20 lbs. a sq. in., which corresponds to an excess pressure of 1 or 1½ atmosphere. If such a pressure cannot be had, no good results are obtained.

This air-compressor is specially constructed for places where the power is derived from the main rod of the pumps. It is considered that 5 or 6 horse-power would be required to drive an air-compressor. In the Perseberg adit the air-compressor is from 60 to 70 fathoms from the end; there is no regulator.

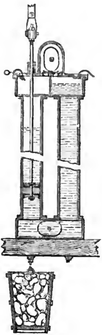
Pipes.—The air is conducted from the compressor along the level by cast-iron flange-pipes, 4 in. in diameter and 9 ft. long, with a small spigot and socket, the joints being made with tar, mixed with finely-powdered brick and lime.

These pipes conduct the air very nearly to the end, and the air is finally brought into the machine by some 30 ft. of india-rubber pipe, 3 in. in diameter and $\frac{3}{16}$ in. thick.

F. B. Doering's rock-boring machine, Figs. 1133 to 1138, has an effective means of regulating

the forward movement of the main cylinder in which the piston carrying the tool works, as the work progresses. A piston-valve *a* regulates the supply of water or other fluid to and its outlet from a pair of cylinders *b b*, attached to the main cylinder *c*, the valve *a* being worked by a piston in a cylinder by motive fluid distributed from the main cylinder to the small cylinder *d*, the piston of which is connected to the valve. Instead of attaching the adjacent cylinders to the boring

1131.



1132.

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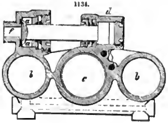

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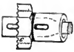

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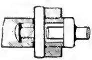
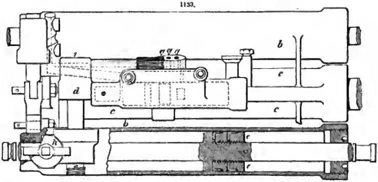


1133.



cylinder, the pistons of these cylinders may be attached to the working or boring cylinder, the adjacent cylinder in this case being fixed. The adjacent cylinders *b b* have each a fixed piston *e*, and a supply of compressed air may be maintained at the front. So much of each of the cylinders as is behind the piston or pistons is filled with water. A tube connected at *f* leads from the piston-valve *a* to a reservoir containing this water or fluid.

The action of the engine is as follows:—Supposing the main cylinder *c* and adjacent cylin-

ders $b\,b$ are at the back end of their travel; whenever the tool, as it continues to work, has cut to a sufficient depth to allow the main piston to uncover a port in the main cylinder communicating with the cylinder of the piston-valve a, this valve moves and allows part of the water in the adjacent cylinders $b\,b$ to escape under the pressure of the compressed air on the other side of the fixed pistons $e\,e$, or under the pressure due to the weight of the machine if the same is working downwards. The adjacent cylinders and main cylinders are thus caused to advance, and this advance takes place intermittently, according to the quantity of water which escapes from the valve, until they reach the forward end of their travel. A cock at the front part of the adjacent cylinders is then opened to let out the compressed air, and pressure is exerted on the water in the reservoir to force the water through the valve into the adjacent cylinders, the small cylinder d exhausting into the main cylinder to allow the valve a to be moved by the pressure of the water, the piston of the main cylinder being put into the required position. The pressure of the water in the adjacent cylinders causes them and the main cylinder c to run back on their supporting-bars to recommence their forward travel; the valve a is then closed, the cock at the front end of the adjacent cylinders reversed, and the pressure in the water reservoir removed.

When the engine is working vertically or nearly so, the employment of compressed air in the adjacent cylinders may be dispensed with, as the weight of the engine will be sufficient to effect the feed as the tool cuts. Again, instead of compressed air in the adjacent cylinders, a vacuum may be created in the water reservoir connected with the valve. This application of water to regulate the advance of a boring engine may be applied directly to the advance of the boring-tool, as shown in Fig. 1137, the cylinder a being stationary, and the piston-rod b forming a cylinder in which a piston c attached to the boring-tool moves. Water is placed in the front portion of the piston-rod at f, and a pressure of the motive fluid acting on the back of the piston being constantly supplied through h to keep it pressed against the water so as to advance when the water or a portion of it is discharged through k. In this case, the valve for the discharge is formed by the piston. This discharge can only take place when the tool has penetrated to such a depth as to allow the port k to communicate with m. A circular groove is cut in the piston at k to regulate or adjust the engine for working in materials of different hardness or softness.

The ports $g\,g\,g$, Fig. 1133, in the main cylinder are formed at various distances from the cylinder end, and communicate with the passage leading to the advance cylinder d through a cock common to all these ports. According to whether the material operated upon necessitates a short or long stroke, the cock is turned to open the way between the advance cylinder and one or other of the ports, to produce the advance of the engine when the main piston has passed this port in its stroke. Instead of employing a cock common to all these ports, the inventor has provided plugs by which he can close all the ports except the one required for work. It is also sometimes desirable to alter the position of the ports in the main cylinder for working the valve; this may be effected by a cock h arranged similarly to that before described, or the communication between the cylinder and its valve-piston may be throttled or *wire-drawn*.

For the purpose of securing the tool in the end of the piston-rod, Doering threads the end of the piston-rod to receive a nut a, Fig. 1135, and makes the position of the ordinary key b adjustable. The nut a is screwed up and the key driven in, thus enabling him to dispense with the washers usually employed. In some cases grooves c, Fig. 1136, are formed in the nut to keep it from turning. A nut is also employed on the inner end of the tool-head, Fig. 1138, and the main piston-rod formed hollow so as to pass the tool down it and secure it by a nut and key, as in Fig. 1135.

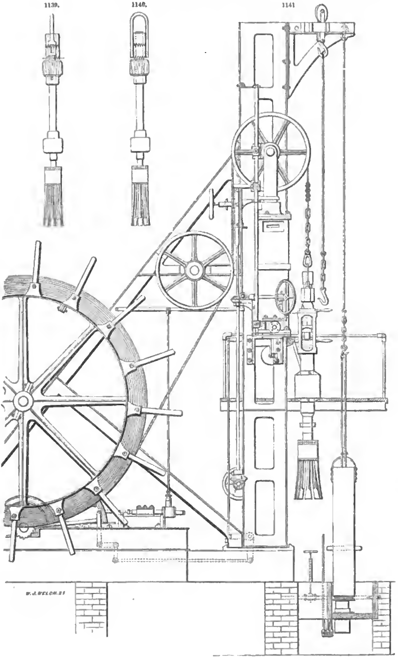
Mather and Platt's Boring Machine.—The construction of the boring-head and shell-pump, and the mode of acquiring the percussive motion, constitute the chief novelties of the system and machine, shown in Figs. 1139 to 1142. The couple-cylinder engine, with the reversing or link motion, is used for winding and lowering the apparatus; but an ordinary winding engine, similar to those used in collieries, may be applied.

The boring-head consists of a wrought-iron bar, about 8 ft. long, on the lower part of which is fitted a block of cast iron, in which the chisels or cutters are firmly secured. Above the chisels an iron casting is fixed to the bar, by which the boring-head is kept steady and perpendicular in the hole. A mechanical arrangement is provided, by which the boring-head is compelled to move round a part of a revolution at each stroke. The loop or link by which the boring apparatus is attached to the flat wire rope is secured to a loose casting on the wrought-iron bar, with liberty to move up and down about 6 in. A part of this casting is of square section, but twisted about one-fourth of the circumference. This twisted part moves through a socket of corresponding form on the upper part of a box, in which is placed a series of ratchets and catches, by which the rotary motion is produced. Two objects are here accomplished—one the rotary motion given to the boring-head, the other a facility for the rope to descend after the boring-head has struck, and so prevent any slack taking place, which would cause the rope to dangle against the side of the hole, and become seriously injured by chafing.

The shell-pump, Fig. 1141, is a cylinder of cast iron, to the top of which is attached a wrought-iron guide. The cylinder is fitted with a bucket similar to that of a common lifting pump, with an india-rubber valve. At the bottom of the cylinder is a clack, which also acts on the same principle as that in a common lifting pump, but it is slightly modified to suit the particular purpose to which it is here applied. The bottom clack is not fastened to the cylinder, but works in a frame attached to a rod which passes through the bucket, and through a wrought-iron guide at the top of the cylinder, and is kept in its place by a cotter, which passes through a proper slot at the top of the rod. The pump-rod, or that by which the bucket is worked, is made of a forked form, for the twofold purpose of allowing the rod to which the bottom clack is attached to pass through the bucket, and also to serve as the link or loop by which the whole is suspended.

The wrought-iron guide is secured to the top of the cylinder, and prevents the bucket from

1139. 1140. 1141.



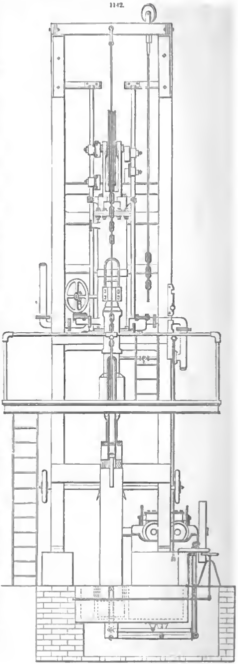
being drawn out when the whole is so suspended. The bottom clack also is so arranged that it is at liberty to rise about 6 in. from its seating, so as to allow large fragments of rock, or other material, to have free access to the interior of the cylinder when a partial vacuum is formed there by the up-stroke of the pump.

The percussive motion is produced by means of a steam-cylinder, which is fitted with a piston of 15 in. diameter, having a rod of cast iron 7 in. square, branching off to a fork, in which is a pulley of about 3 ft. in diameter, of sufficient breadth for the rope to pass over, and with flanges to keep it in its place. As the boring-head and piston will both fall by their own weight when the steam is shut off and the exhaust-valve opened, the steam is admitted only at the bottom of the cylinder; the exhaust-port is a few inches higher than the steam-port, so that there is always an elastic cushion of steam of that thickness for the piston to fall upon.

The valves are opened and shut by a self-acting motion derived from the action of the piston itself; and as it is of course necessary that motion should be given to it before such a result can ensue, a small jet of steam is allowed to be constantly blowing into the bottom of the cylinder; this causes the piston to move slowly at first, so as to take up the rope, and allow it to receive the weight of the boring-rod by degrees, and without a jerk. An arm which is attached to the piston-rod then comes in contact with a clam, which opens the steam-valve, and the piston moves quickly to the top of the stroke. Another clam, worked by the same arm, then shuts off the steam, and the exhaust-valve is opened by a corresponding arrangement on the other side of the piston-rod. By moving the clams, the length of the stroke can be varied at the will of the operator, according to the material to be bored through. The fall of the boring-head and piston can also be regulated by a weighted valve on the exhaust-pipe, so as to descend slowly or quickly, as may be required.

The general arrangement of the new machine may be described as follows:—The winding-drum is 10 ft. in diameter, and is capable of holding 3000 ft. of flat wire rope, 4½ in. broad and ½ in. thick; from the drum the rope passes under a guide-pulley, through a *clam*, and over the pulley which is supported on the fork end of the piston-rod, and so to the end which receives the boring-head, which being hooked on and lowered to the bottom, the rope is gripped by the clam. A

1142.



small jet of steam is then turned on, causing the piston to rise slowly until the arm moves the clam, and gives the full charge of steam; an accelerated motion is then given to the piston, raising the boring-head the required height, when the steam is shut off, and the exhaust-valve opened in the way described, thus effecting one stroke of the boring-head as regulated by a back-pressure valve in the exhaust-pipe. The exhaust-port is 6 in. from the bottom of the cylinder; when the piston descends to this point it rests on a cushion of steam, which prevents any concussion. To increase the lift of the boring-head, or compensate for the elasticity of the rope, which is found to be 1 in. in 100 ft., it is simply necessary to raise the clams on the clam-shaft whilst the percussive motion is in operation. The *clam* which grips the rope is fixed to a slide and screw, by which means the rope can be given out as required. When this operation is completed, and the strata cut up by a succession of strokes thus effected, the steam is shut off from the percussive cylinder, the rope unclamped, the winding engine put in motion, and the boring-head brought up and slung from an overhead suspension-bar by a hook fitted with a roller to traverse the bar. The shell-pump, Fig. 1141, is then lowered, and the *débris* pumped into it, by lowering and raising the bucket about three times, which the reversing motion of the winding engine readily admits of; it is then brought to surface and emptied by the following very simple arrangement. At a point in the suspension-bar a hook is fixed perpendicularly over a small table in the waste tank, which table is raised and lowered by a screw. The pump being suspended from the hook hangs directly over the table, which is then raised by the screw till it receives the weight of the pump. A *cotter*, which keeps the clack in its place, is then knocked out, and the table screwed down. The bottom clack and the frame descending with it, the contents of the pump are washed out by the rush of water contained in the pump-cylinder. The table is again raised by the screw, and the clack resumes its proper position; the *cotter* is then driven into the *slot*, and the pump is again ready to be lowered into the hole as before. It is generally necessary for the pump to descend three times, in order to remove all the *débris* broken up by the boring-head at one operation.

The following facts obtained from the use of the machine in boring in the new red sandstone at Manchester, will show its actual performance, and enable us to compare it with the other systems. The boring-head is lowered at the rate of 500 ft. a minute; the percussive motion is performed at the rate of 24 blows a minute, and being continued for ten minutes, the cutters in that time penetrate from 5 to 6 in.; it is then wound up at 300 ft. a minute. The shell-pump is then lowered at the rate of 500 ft. a minute, the pumping continued for one minute and a half, and being charged, the pump is wound up at 300 ft. a minute. It is then emptied and the operation repeated, which can be accomplished three times in ten minutes, at a depth of 200 ft. The whole of one operation, resulting in the deepening of the hole 5 to 6 in., and cleansing it of *débris* ready for the cutters or boring-head being again introduced, is seen to occupy an interval of 20 minutes only.

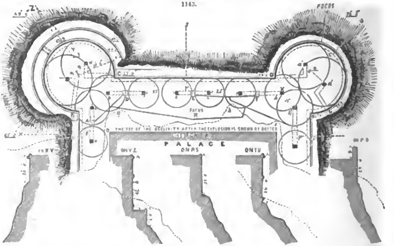
Blasting.—Gunpowder is the most valuable agent for excavation; it is, however, of more service in the work of extraction than in that of preparation, because in removing the minerals those regular forms of the wells are not required which distinguish the shaft and the drift from the gallery. Blasting-powder is employed in different quantities and in various forms, according to circumstances. In slaty open rock, in rotten brittle shale, and in loose gravel, it is of no use; but in hard rock, in sandstone, limestone, and similar substances, blasting is extremely serviceable, and often reduces the prices of working hard rock to that of soft material. Gunpowder is of most service where the vein has a seam of soft mineral, or a succession of cavities on one side, so that a blast applied at the opposite termination of the vein may remove the whole thickness of it. If the soft matter or the cavities are in the middle of the vein, it requires always two blasts, and of course the drilling of two holes, as well as two charges of gunpowder, to remove the vein. The amount of gunpowder used is often calculated to be proportionate to the amount of rock removed, but this is not so in practice; where the amount of matter removed is limited, the consumption of powder increases more rapidly than the quantity of rock removed. In mines which have a large quantity of shattered rocks, the application of powder is limited by the consideration that injury may be caused to other parts of the mine. The removal of thick veins, or masses, of heavy rock, also veins of pyrites, is often conducted with considerable difficulty, because heavy blasts cannot conveniently be applied. In all such cases it is, however, the cheapest way of working masses; and if holes for blasting cannot well be drilled, they can be formed by acids. Pyrites may be penetrated by nitric or muriatic acid; also native metals, such as copper, limestone, and magnetic iron ore, may be dissolved by any acid—the muriatic is, however, the most generally used. In this case we cannot sink any other form of hole than a vertical one. The manipulation is easily performed by setting a glass tube vertically upon the rock, and providing its top with a funnel and apparatus, so as to let in the acid drop by drop. If the pipe is close fitting to the rock, and the acid poured in very slowly, the hole will not be much larger than the glass-pipe. The tube must descend with the bottom of the hole, and be always close to it. This operation works very slowly; but in pyrites, or compact magnetic iron ore which cannot be penetrated by steel tools, it is a useful method of preparing a hole for blasting. When heavy masses are to be detached by one charge, the hole may be made wider in the bottom by letting down the acid more rapidly, which will spread over a larger surface and dissolve a greater width. See GUNPOWDER.

We will now give one example of firing charges of gunpowder by means of a fuze, and another by a voltaic battery.

Demolition of a Fort at Furruckabad, in January, 1858: by P. H. Scratchley, R.E.—The fort ordered to be destroyed was a front built of good sound brick masonry, consisting of two solid towers, the left one being 54 ft. in height and the other 36 ft. high, and both being 54 ft. in diameter, connected by a revetted curtain 130 ft. long and 34 ft. in height; two portions of revetment, 30 ft. in length, running at right angles to the curtain, from the towers on each side, and of nearly the same height as the curtain; and also a wall 160 ft. long, 11 ft. high, and 2 ft. thick, forming part of an enclosed court-yard. L is put = the length of the line of least resistance in feet.

The project for the demolition of the front was as follows:—Two charges, with lines of least resistance 18 ft. long, to be placed in each of the towers, 3 ft. in advance of their centres, and at one-lined intervals, Figs. 1143 to 1148. Two charges, with L = 12 ft., to be placed in each tower

1143.



1144. 1145. 1146. 1147. 1148.

in rear of the angles formed by the tower and the revetment. The remaining portion of the connecting-curtain to be destroyed by charges, with L = 10 ft., placed at 2½-lined intervals, which required 6 more, as shown in Fig. 1143.

In the towers, galleries with returns were to be driven at nearly equal levels, which the nature of the ground favoured. The mines in the revetment were to be formed by sinking 5 shafts, each 15 ft. deep, with galleries running out right and left from them to the requisite distances.

The charges were calculated according to the formula for strong masonry revetments without counterforts, placed at two-lined intervals, or $\frac{3}{20} L^3$. As native powder was to be used, there was allowed $\frac{1}{5}$ of $\frac{3}{20} L^3$, or $\frac{3}{100} L^3$, in addition to the proper charges of English powder, making the formula $\frac{3}{20} L^3 + \frac{3}{100} L^3 = \frac{18}{100} L^3$.

Scratchley was also directed to prepare the towers at the entrance gateway for demolition, and he carried out the following plan. These towers were 28 ft. in diameter, and from 22 ft. to 29 ft. high on the outside: they were built of softer masonry than the others, and were solid only to a height of 15 ft. from the bottom. A shaft was to be sunk in the centre of each tower, at the level of the ground inside (15 ft. from the bottom), 12 ft. deep; and small galleries were to be driven right and left, 5 and 6 ft. long respectively. The charges were calculated, as above, by the formula $\frac{18}{100} L^3$, and were to be placed so that their lines of least resistance were respectively 8 and 9 ft. long.

The following journal gives the particulars of the work executed.

A detail of officers and men of the Engineer Brigade left the camp at Futtehghur at 3 P.M., 5th January, 1858:—

Corps.	Officers.	Native Officers.	Sergeants.	Corporals.	Privates.	Bugler.	Total.	Remarks.
Royal Engineers	3	..	2	5	52	1	63	Lieut. Scratchley, R.E.
Bengal Engineers	2	..	..	..	..	..	2	" Wynne, R.E. " Keith, B.E.
Bengal Sappers and Miners ..	..	2	4	..	33	..	39	" Lang, B.E. " Forbes, B.E.
Total	5	2	6	5	85	1	104	

This detail was divided into 3 reliefs, namely:—

1st relief—20 rank and file, European.
12 " Native.
2nd relief—19 " European.
12 " Native.
3rd relief—18 " European.
12 " Native.

The 1st relief commenced work at 8 P.M. on the evening of January 5th.

January 5th, 1st Relief, 8 till 12 P.M., Wynne.—4 galleries, marked B, C, G, H, Fig. 1143, were commenced in the towers, at the respective levels of 26 ft. 6 in., 27 ft. 6 in., 29 ft. 6 in., and 29 ft. 6 in., below the terreplein of the fort, and driven towards the centre of each tower. 4 shafts, A, D, E, F, were also commenced at a distance of 10 ft. from the curtain wall.

January 6th, 2nd Relief, 12 till 4 A.M., Keith.—Shafts A, D, E, F, were completed to the depth of 15 ft. each, and were made 4 ft. by 3 ft. Galleries running parallel to the wall were commenced right and left of each shaft. Soil very easy, being made earth. Galleries B, C, G, progressed slowly through very tough pucka masonry. That at H was softer.

3rd Relief, 4 till 8 A.M., Lang.—The 8 galleries of A, D, E, F, progressed rapidly through made earth. The galleries B, C, G, advanced through tough masonry, and H through soft masonry. The tools were in bad order and were not adapted to mining.

1st Relief, 8 till 12 A.M., Forbes.—The 8 galleries progressed rapidly. The gallery H was cut through pucka masonry, 7 ft., and reached rubble. The progress at B, C, G, was slower.

2nd Relief, 12 till 4 P.M., Wynne.—The 8 galleries were nearly finished:—

		Ft.	In.	
That at B	had advanced	9	0	through pucka masonry.
" C	"	8	6	"
" G	"	3	0	"
" H	"	12	0	through made earth.

3rd Relief, 4 to 8 P.M., Keith.—The galleries of A, D, E, F, were finished to the following lengths:—

	Ft.	In.		Ft.	In.
A *c* (Fig. 1143) ..	12	0	E *c'* (Fig. 1143) ..	12	6
A *b* " ..	13	6	E *c* " ..	12	6
D *b*¹ " ..	14	0	F *c* " ..	12	6
D *c* " ..	12	6	F *b*¹ " ..	20	0

Hardly any progress was made at G.

1st Relief, 8 till 12 P.M., Lang.—Another shaft I, Fig. 1143, was commenced at a distance of 10 ft. from the wall. A party was also employed in lodging charges in the wall to be destroyed, described in accompanying memorandum.

January 7th, 2nd Relief, 12 P.M. till 4 A.M., Forbes.—

B gallery was 24 ft. long.
C " 24 "
H " 17 ft. 10 in., and return commenced.
G had not extended through pucka masonry.

3rd Relief, 4 till 8 A.M., Wynne.—Shaft I was completed to a depth of 15 ft., and 2 galleries were commenced from it, running right and left parallel to the wall.

1st Relief, Keith.—The galleries of shaft I were completed to the required lengths, namely, *b*², 14 ft., and *c*, 12 ft. Chambers were formed in all the shaft-galleries.

B gallery was completed, with a return 5 ft. 8 in. long.
C " " " " 7 ft. long.
At G the work was continued by blasting.
H gallery was completed, with a return 6 ft. long.

2nd Relief, 12 till 4 P.M., Lang.—The chambers in all the galleries except G were completed. G was 8 ft. 5 in. long, pucka masonry 7 ft. thick having been cut through. More experiments were made on the wall of the court-yard.

3rd Relief, 4 till 8 P.M., Forbes.—More charges were tried on the wall, and a party was employed destroying it by hand.

1st Relief, 8 till 12 P.M., Wynne.—Shafts A and B were sunk 12 ft. deep in the entrance towers.

January 8th, 2nd Relief, 12 till 4 A.M., Keith.—Galleries were driven from shafts A and B, right and left, 7 ft. and 9 ft. long respectively.

3rd Relief, 4 till 8 A.M., Lang.—A party of men was employed in demolishing the wall. Chambers were prepared and bamboos laid (as in all the other mines) for the entrance-tower mines. The whole of the mines were now ready for loading, but the powder had not yet arrived.

9th January.—At 3 P.M. this afternoon the party of Engineers, after carefully closing all the openings of the shafts and galleries, was marched back to Futtehghur camp.

Remarks.—The whole of the work had thus been carried on without interruption, the soil being very easily worked, and being evidently all made earth. No sheeting had been required, excepting in the left gallery at the right entrance tower, where the earth fell in. The whole of the mines were ready for charging *in forty-eight hours*, with the exception of that in gallery G, where the pucka masonry gave great trouble. The dimensions of all the galleries were 3 ft. 6 in. by 2 ft. 6 in.

13th January.—A detail of the Engineer Brigade left camp at 5.30 A.M. to load the mines at the Fort, namely, 2 officers, 2 sergeants, and 82 rank and file; and 1 officer, and 24 native sappers. 12 of the sappers were, however, afterwards withdrawn to be employed elsewhere.

The charges were placed as follows:—

In B gallery at *a*¹	1050	lbs. of	Native	powder.
C " *a*	800	"	English	"
	99	"	Native	"
G " *a*	874	"	English	"
H " *a*¹	1050	"	Native	"

A shaft at	c	.. ..	180 lbs. of Native powder.	
	b	.. ..	310 „ „ „	
D „	b^1	.. ..	310 „ „ „	
	c	.. ..	180 „ „ „	
E „	c'	.. ..	180 „ „ „	
	c	.. ..	180 „ „ „	
F „	c	.. ..	180 „ „ „	
	b^1	.. ..	258 „ English „	
I „	b^2	.. ..	258 „ „ „	
	o	.. ..	180 „ Native „	

Approximation.—For English powder and length of 16 ft. of least resistance, we have 16 cubed = 4096, and $\frac{15}{100}$ of 4096 = 614 lbs. of gunpowder, which may be put = 620, the half of which is 310 lbs.

The charges were placed in boxes where practicable, the hose was laid in bamboos, and the whole was carefully tamped.

The galleries took most time in loading and tamping, and were not ready till 7 P.M., whilst the shafts were finished by 4 P.M.

The firing was put off till the next morning, when the hoses of all the shafts were brought to one focus R. There was one focus for each tower, the length of hose for each being 5 ft. less than that for the upper focus, to allow, if possible, a few seconds elapsing between the two explosions. The hose was lighted at the three foci at the same time, at the sound of the bugle, and the explosions were very nearly simultaneous, with the exception of that of one mine, marked X, Fig. 1143, which did not take place till 30 seconds after the others.

The demolition was complete, and the object desired was attained, which was to leave a pretty practicable ramp from the outside into the interior.

There is no doubt that if more time had been allowed, or more men had been procurable, the demolition might have been effected by the expenditure of one-half of the quantity of powder used; but it must be borne in mind that Scratchley's instructions were to have everything ready *in forty-eight hours*, and native powder was to be had in abundance.

The mines at the entrance gateway were not loaded, but remained ready to be charged at some future time.

Statement of the Expenditure of Powder, Hose, &c.

2 charges of	1050 lbs.	each,	total	2100 lbs.,	Native powder.
1 „	874, 800	„	„	1674 lbs.,	English „
1 „	99	„	„	99 lbs.,	Native „
6 „	180	„	„	1080 lbs.,	„ „
2 „	310	„	„	620 lbs.,	„ „
2 „	258	„	„	516 lbs.,	English „

Total, 2190 lbs. of English powder.
„ 3899 lbs. of Native „
„ 848 feet of ½-inch hose.
„ 2 port-fires.

Taking the line of least resistance = 18 ft., then 18 cubed = 5832, and $\frac{18}{100}$ of 5832 = 1050 lbs. of powder nearly. The other charges were calculated in a similar manner.

Memorandum.—Partial Destruction of a Wall by means of Small Charges.—This wall was 11 ft. high, 2 ft. thick, and about 160 ft. long. There were two piers, 6 ft. square, one on each side of an entrance at the centre of the wall; these were built much better than the remainder of the wall, which had been constructed with bricks and a little mud, mortar being found only in the foundation.

Ten charges, of 5 lbs. each, were placed along the wall, at intervals of 10 ft., and were lodged as nearly as possible 2 ft. below the surface of the ground, and under the centre line of the wall. One charge of 10 lbs. was placed in each pier, 2 ft. 6 in. below the level of the ground, and under its centre.

The piers were completely thrown down, without violence: all the other charges, with the exception of three, failed; some blowing out the tamping and making a small breach in the wall, others throwing out the foundation and earth on the other side, but failing to bring down the wall, or any part of it. Four more charges, of 5 lbs. each, were placed equidistant between the former, which completely destroyed the part where they were lodged.

The remainder of the wall was picked and thrown down by about twelve men in a very short time, and other portions of the walls around were thrown down in the same manner.

The powder made use of was native, and undoubtedly of inferior strength to that of European manufacture.

Blasting was not tried, as the nature of the wall did not admit of it. Had Scratchley known that it was so very rotten, he would have had the whole of it picked down.—'*Papers of the Corps of Royal Engineers*,' vol. viii.

Bickford's fuze is generally employed in blasting operations. See FUZE-MAKING MACHINE.

Blasting with Large Charges of Gunpowder at Holyhead, 1860; *by Col. Hamilton, R.E.*—The quarries, opened and worked for the harbour-works, were situated on the declivity of the Holyhead Mountain, at about 1500 yds. distance from and in rear of the land end of the breakwater; the portion thereof, 120 ft. by 40 ft., and 90 ft. in height, on this occasion operated on, was formed of quartzose schist, extremely hard, and weighing about 1¾ cwt. to the cubic foot, stratified in lines extending from N.E. to S.W., a little overhanging to S.E., but nearly vertical, with numerous joints in that and other directions throughout the whole mass.

An entrance gallery, Figs. 1149, 1150, 5 ft. 6 in. by 3 ft. 6 in., was driven from the face of the rock, commencing at a height of 12 ft. above its base, with a view to gain an efficient line of tamping resistance, a favourable joint in the line of strata having been taken advantage of to the extent of 34 ft., where a shaft, 3 ft. 6 in. by 3 ft. 6 in., was sunk to the depth of 14 ft. 6 in.; from this, level galleries, 5 ft. 6 in. by 3 ft. 6 in., were driven right and left, the former to the extent of 49 ft. 9 in., and the latter 56 ft. 6 in., with a length of 43 ft. 6 in. of headings and chambers of similar dimensions, as illustrated in the accompanying plan and elevation. The galleries, shafts, and so on, were worked out by blasting, necessitated by the hard nature of the rock; and the increased size given to these communications above that generally adopted was with a view to enable the miners to strike with more freedom and effect, the extra excavation being more than compensated by the facility of working. The chambers were formed by slightly enlarging the short return-headings, and were placed from 2 to 3 ft. below the level of the ground or rail line in front of the quarries, to ensure the bottoms of the face acted upon being well lifted, as want of attention to this particular before a former explosion led to considerable subsequent labour in removing a portion of stone left standing.

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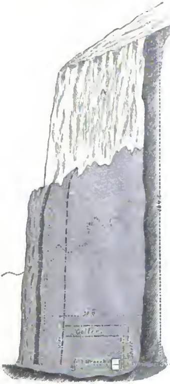

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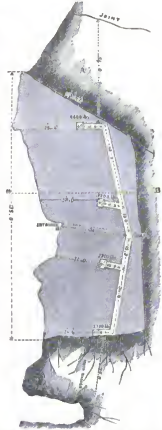


The gunpowder used was similar to the fine grain Government powder, its strength having been previously tested by projecting with a $1\frac{1}{2}$-oz. charge a 68-lb. shot, from a mortar at an angle of 45°, to the distance of 480 ft.; the charges were placed in canvas bags well coated with tar, 2000 or 3000 lbs. in one bag, and the remainder in smaller bags, and so respectively lodged in each chamber.

The tamping was executed throughout with a sort of stiff red clay obtained in the vicinity, used in a slightly moist state, well rammed up to the entrances of the chambers, and close to the bags of gunpowder, merely leaving a small air space round the latter, and was continued

to the mouth of the gallery in the face of the rock: it apparently answered its intended purpose admirably.

The battery employed to fire the charges was that known as Grove's. It had 32 cells, and platinum plates, 8 in. by 6 in., in nitric acid, in porous cells surrounded by diluted (6 to 1) sulphuric acid; it was placed on the top of the cliff, and directly in rear of the line of chambers, 300 ft. distant from the upper edge of the former; two copper wires connected the battery with each charge, extending from the latter through the galleries directly up the face of the cliff and on to the cells, where the four positive were united, as well as the four negative. To the extremities of the copper wires at the charges were attached platinum wire about ¼ in. in length, protected by a wooden block, round which block a small bag of fine or sporting powder was tied and introduced into the large bags of powder before mentioned.

The total quantity of powder used in the explosion was 12,000 lbs., placed in four charges, amounting respectively to 4000, 3000, 2300, and 2700 lbs., with lines of least resistance 29 ft., 32 ft., 22 ft., and 24 ft. 6 in., as shown in Figs. 1149, 1150; these respective charges were not calculated by any specific formula founded on the lengths of the lines of least resistance, but a certain number of pounds of gunpowder a ton of rock to be removed was allowed, according to the particular features and tenacity of the portion to be acted on (in the present instance 1 lb. of gunpowder to 3 tons of rock); this calculation was based upon the experience gained from numerous previous explosions of a similar character carried out at different parts of the quarries. In some cases, 1 lb. of gunpowder was found sufficient to remove only 2 tons, in other cases it has proved adequate to displace 4 tons of stone.

Shortly after the hour appointed (twelve o'clock), the mines were fired on a signal with most successful results; the rock a little above its base was seen to bulge slightly outwards, and then tumble to pieces, emitting much smoke, and the superincumbent mass gently sliding down, separated into various sized blocks; a perfect volley of small stuff, mostly the tamping, shot horizontally along, close to the ground, directly in front of the face of rock, to a distance of about 250 ft., covering the surface with a coating of fine damp clay, separated into small particles like sand; no stones of any magnitude were thrown out beyond the general *débris*, which was confined to a width of 125 ft. from the original face of the quarry.

The total quantity of rock removed was about 40,000 tons, which gives 3⅓ tons to the pound of gunpowder used. The report on the effect of a similar explosion in January, 1857, shows that 7½ tons the pound of gunpowder were then brought down, or nearly double the quantity removed by each pound on this occasion; and on reference to the accompanying plan it will be observed that if, instead of the charge of 4000 lbs., a smaller one had been employed, the effect would probably still have extended as far as the joint at that end, and also that a slight addition to the charge of 2700 lbs. at the other end would have caused the fall of all the portion as far as the recess, which is described as much shaken. It may also be remarked that the cliff brought down in January, 1857, was 25 ft. higher than that here described; also that the strata of the former were horizontal, whilst those of the latter were vertical; and, on the other hand, that the blocks forming the *débris* of the latter were smaller, and more suitable for building, than those of the former; it is evidently, therefore, difficult to fix any rules for determining the quantity of powder required, especially where hidden joints exist which limit its effects.

The miners were but little impeded by wet or damp; the gallery was driven with a slight inclination upwards to allow any water met with to find its way out. Whenever damp holes had to be fired, pitched bags or cases, capable of holding 3 to 5 oz. charges, were used; the smoke from the firing of the blasts and foul air were removed by a rotatory blower worked by a boy at the mouth of the heading, and a canvas pipe conveyed the fresh air to the chambers.

The powder was brought to the mouth of the gallery in casks (containing from 50 to 100 lbs.), and there emptied into canvas bags capable of holding 50 lbs.; these bags were then passed from hand to hand by men placed at intervals in the galleries, to the respective chambers, where they were discharged into larger bags previously lodged there, to the extent required, after which some old powder-cask sackings were thrown round and over them.

The clay for tamping was brought to the mouth of the main gallery in wagons, and wheeled through it on planks to the shaft, where it was thrown down, and conveyed from the bottom thereof in a similar manner to the headings. This method was found to require less time and labour than any other known to the engineer. The whole of the tamping was performed in 42 hours by 25 labourers.

The copper wires leading from each charge were, throughout their course in the tamping, lapped round with calico and tar-bands, great care having been taken when tamping about them. This method was preferred to that of using wooden casings, and gave much freedom and ease in turnings at the angles and bends in the headings.

Grove's Battery.—32 porous cells; 32 zinc plates; 32 platinum plates; 32 gutta-percha troughs; mahogany case for box, quicksilver, and poles; 2½ gallons nitric acid to fill the cells; ½ gallon sulphuric acid.

Wires.—8 copper wires from the battery to the charges, including calico lapping and tar-bands:—8×500 ft. = 4000 ft., and 800 ft. of wire weighing 28 lbs., 4000 ft. = 140 lbs.

The time occupied in driving the galleries, shafts, and so on, was about 9 months, the rate of progress averaging 1 foot the day of 24 hours, and 8 miners working. Powder used in blasting (3 lbs. a foot), $210 \times 3 = 630$; 1 in. of fuze a foot = 210 ft.; 6 lbs. of candles a week, $36 \times 6 = 216$; 30 bags or tarred cases.

Thus it would appear that 40,000 tons of stone were procured at an expense of 669*l.* 10*s.* 6*d.*, or about 4*d.* per ton.

At a point 150 yards in front of the cliff, the report was not loud, it resembled the sound of very distant thunder.

Application of the Galvanic Battery to Military Purposes. Taken from H. Ward's paper, 'Profes-

sional Papers, R.E.,' 1855.—The inquiry, whether the explosion of charges of powder by voltaic agency could be made generally applicable to engineering purposes in the field, seems naturally to divide itself into the following heads:—An inquiry

1st. Into the motive power.

2nd. Into the conducting medium, or the means by which that power could be conveyed to a distance.

3rd. The construction of bursting charges to produce the desired explosion.

4th. How the power obtainable could be best applied to the explosion of a number of mines simultaneously.

Motive Power.—The inquiry into the motive power arranges itself under the following subdivisions:—

1st. The determination of the principle by which voltaic action could, on the whole, be most effectually produced: that is, the determination of that combination of metals and acids which, while it comprises such as are generally procurable at a moderate expense and are safe to handle, would exhibit the greatest power.

2nd. The most *economical* arrangement of these, as to size and numbers; so that the power required should be produced out of the smallest bulk, and at the least cost.

3rd. The general *simplification* of the arrangement of cells and plates, so as to admit of their easy repair or replacement; the arrangement to combine portability and facility in charging and dismantling; the whole to admit of being readily packed and put together; to be durable, having as few parts as possible liable to deterioration by keep or use, and those such as to admit of many spare ones being carried with the apparatus, and easily procurable anywhere.

4th. To reduce the manipulation to a mere mechanical process, requiring in the application no chemical or scientific knowledge to work it effectually.

Conducting Medium.—The inquiry respecting the conducting medium naturally embraces the best metal for the purpose and the most desirable thickness under every circumstance; a ready mode of ascertaining the conducting power of any description that might be procured on the spot in an emergency; the degree of isolation required to preserve the strength of the circulating current, the best covering to effect this perfectly, and the cost of the most approved.

Bursting Charges.—The most approved bursting charge to be ascertained; whether that formerly made with a thin platinum or iron wire, or that discovered by Brunton, where an inflammable compound is obtained seemingly by a combination of copper, sulphur, carbon, and gutta-percha.

In the former, the best length and thickness of platinum or iron wire, and the most desirable construction for bursting charges under such circumstances; in the latter, the most approved compound, and the readiest method of making it.

Simultaneous Firing.—How far the power obtainable by voltaic agency can be applied to the explosion of a number of charges simultaneously by each description of bursting charge, and the best arrangements for this purpose; the rules deduced from scientific inquiry that should be the guide in considering such arrangements, and how far they must be modified in practice.

As the whole of the investigation is based on the theory of voltaic circuits, propounded by Professor Ohm, of Nuremberg, of which a translation is to be found in Taylor's 'Scientific Memoirs,' June, 1840, we cannot expect to be generally intelligible, unless we preface the experimental results with a notice of the principles established by him, and the conclusions deducible therefrom.

In considering a voltaic arrangement of one pair, say zinc, platinum, and dilute sulphuric acid with the circuit closed, Ohm has shown that the force of the current in circulation is directly as the sum of the electro-motive forces, and inversely as the sum of the resistance to its circulation.

By the sum of the *electro-motive forces* is meant the excess of affinity of the zinc for one of the elements of the solution, as, for example, the oxygen of the water in the above case, over all other counteracting agencies: this force therefore being *entirely independent of the size of the plate*, and subject solely to the nature of the metals and liquids in voltaic combination.

By the term excess of affinity it is understood that if zinc is put in sulphuric acid and water, the zinc decomposing the latter, the cause of the decomposition must be that the affinity of the zinc for oxygen is in excess of that of the hydrogen for the oxygen, with which it is in the first place combined. It is this excess that in this particular case is called the sum. In many combinations of metals and liquids, as in a Daniell or Grove, this excess is the result of more complicated forces, but in all cases the sum of the electro-motive forces is intended to express this excess.

By *resistance* is intended the obstacle opposed to the passage of the electric current by the substances through which it has to pass. It is the inverse of what is termed conducting power. We are in the habit of talking of conducting instead of resisting power, but it will be acknowledged an equally accurate conception, to view all conducting media in the light of resistances opposed to the passage of electricity, as to consider them conductors aiding its circulation. No substances in nature are perfect conductors, consequently some electric excitement is lost in each step of the transmission from particle to particle; and it seems as rational therefore to ascribe the loss experienced to a resisting agency, as to attribute the quantity obtained to a favouring one.

Let F then represent the force of the current in circulation, which it must be remembered, from what has been before stated in the first part of this paper, is equal in all parts of the circuit. Let E = the sum of the electro-motive forces, and R = the sum of the resistances. Then

$$F = \frac{E}{R}. \qquad [1]$$

The resistance R in an ordinary voltaic pair is made up of two principal and some inconsiderable portions. The former include the resistance of the wire completing the circuit, and that of the liquid intervening between the plates.

The resistance of the conducting wire which we call w, varies directly as its length (l), and its specific resistance (s); and inversely as the area of its section (a). Or,

$$w = \frac{s\,l}{a}. \qquad [2]$$

The resistance of the intervening liquid, which we will call L, varies directly as its specific resistance (S), and the thickness of the stratum (T); and inversely as the surface of the plate in contact with it (A). Or,

$$L = \frac{S\,T}{A}. \qquad [3]$$

By specific resistance is meant the resistance due to the nature of the liquid employed, and the term is used in the same sense as we speak of specific gravity.

In fact, Ohm assumes that every atom, whether of liquid or wire, is capable of receiving excitement from the one before it in the circuit, and parting with it to the next in succession: that a loss occurs in the transmission depending on the differences of the electric forces existing in the two adjacent atoms; just as in the theory of heat the transmission of caloric between two particles is regarded as proportional to the difference of their temperatures. From this the laws in equations [2] and [3] seem obviously deducible.

There are other resistances in an ordinary voltaic circuit, namely, that of the plates themselves, and of the metallic connections between each pair, when a number are combined in series; but the great sectional area and short length of them make their absolute resistance, when compared with the rest of the circuit, insignificant. They do not require a separate consideration.

The resistance R then consists of L and w, or

$$F = \frac{E}{R} = \frac{E}{L + w}. \qquad [4]$$

Now, instead of completing the circuit by a wire, let the *plates* of a pair be connected by a medium whose resistance is insignificant, and equation [4] becomes

$$F = \frac{E}{L}, \qquad [5]$$

representing the free circulation in a voltaic pair, when $w = o$.

If n such pairs are arranged in series, the first zinc and the last platinum being brought in contact by a substance whose resistance is insignificant, we shall then have a electro-motive forces, but also a resistances; so the value of F will remain unchanged, for

$$F = \frac{a\,E}{a\,L} = \frac{E}{L}; \qquad [6]$$

but there can now be added n times as much resistance of wire as could be borne in equation [4], without diminishing the value of the force F below that which it represented there, for

$$F = \frac{E}{L + w} = \frac{a\,E}{n\,L + a\,w}. \qquad [7]$$

When the galvanic circuit is divided and circulates at the same time through two or more branches, the force of the current through each will be in the inverse ratio of its resistance: thus, if r and r' be the resistances of the two portions or branches of a conducting medium through which the current passes, $\frac{1}{r}$ and $\frac{1}{r'}$ will be the proportional force of the current in each, and their sum $\frac{r + r'}{r\,r'}$ will be that of the current passing through both; therefore $\frac{r\,r'}{r + r'}$ will represent the resistance of a medium that could be substituted for both, and not diminish the amount of circulating force.

It is very important to bear in mind the law relative to divided currents, as it particularly concerns arrangements for simultaneous firing. We are too ready to assume that electricity selects for itself the readiest path, utterly rejecting inferior means of conduction; but with respect to the circulation of voltaic currents, this idea is decidedly erroneous, and the converse is capable of easy practical demonstration.

These are the points of Ohm's theory that most immediately concern us; let us now see what conclusions are deducible from it.

Referring to equation [1], $F = \frac{E}{R}$, it is evident that in a voltaic arrangement, the nature of whose metals and liquids has been decided on, the force F is entirely dependent on the magnitude of R, or the resistance offered to the circulation of the current; as when R decreases, F increases, and when $R = o$, $F = \infty$, which implies that whatever arrangement of plates and acids may be made, if the resistance can be reduced to o, the power obtainable is infinite. That this is true may be explained in this way. It will be remembered that it was shown (see BATTERY) to be essential to the flow of a continuous current, in an arrangement, for example, of zinc, copper, and dilute sulphuric acid, that the zinc should be oxidized, the sulphuric acid should combine with the oxide to form a sulphate, and the salt should be removed by dissolution in water, leaving all things *in statu quo* for a new set of actions. Now, though these are described as subsequent operations, where no restraint is offered, they all take place at the same instant.

Now when $R = o$, the initial force F is dependent on the value of E, which represents the excess of affinity of the positive metal for one of the elements of the solution over all counteracting

agencies, and is therefore limited; but if such an arrangement were made that the limited force should be developed again and again, independent of time, the resultant power, of course, would be infinite. At first view it seems as if the combination of zinc, platinum, and dilute acid, above described, is such an arrangement; and as far as the chemical action is concerned (if we leave out of consideration the adherence of the hydrogen to the negative plate) it certainly is, but there is one great check to the development, which can be diminished, but not got rid of altogether, namely, the resistance of the liquid to the passage of electricity from plate to plate. As there must necessarily be some liquid to produce excitement, so must there be a resistance R; let this but assume a value, and F becomes limited.

The development of an unlimited force F would seem, then, to be prevented by the resistance offered to the circulation of the current. It may be considered that the zinc, for instance, on being continually attacked, and finding a difficulty in getting rid of its excitement, becomes so charged that it resists a further disengagement of electricity, or, which is equivalent, resists further destruction, that is, loses its affinity for oxygen, till it can be restored to a certain state of quiescence. We have a case analogous to this in electricity produced by friction in an electrical machine, where, in order to obtain an unlimited supply of positive excitement from the glass cylinder, to charge Leyden jars, or for other purposes, it is necessary to connect the negative primo conductor with the ground, to carry off a portion of the high negative excitement produced in it by the friction: it being well known that if this was not so connected it would become so highly charged as to resist further disengagement of excitement. I have here given, says Ward, this theoretical view of the varying value of F, to bring before the mind the fact that the force of the current circulating is controlled only by the value of R, and that I conceive it to be true that, *without any limitation*, so long as R is decreased F will increase.

The value of R is, as has been stated, composed of two parts, namely, the resistance of the exciting liquid and of the metallic wire closing the circuit; and how these can be diminished in a simple voltaic pair we shall find by referring to equations [2] and [3].

From equation [3] we can diminish the resistance of the liquid stratum, by bringing the plates nearer together, by substituting an exciting solution whose specific resistance is less, or by increasing the size of the plates in each cell.

From equation [2] the resistance of the conducting wire in a simple voltaic pair can be diminished, by substituting a metal whose specific resistance is less, by shortening the length of the wire, or by increasing the area of its section.

Diminishing the distance between the plates in each cell by one-half or one-third will permit us to diminish the size of each plate, *and therefore their weight*, by one-half or one-third, without a loss of power.

Increasing the section of the conducting wire, or, which is the same thing, increasing its weight per yard, will permit its length to be similarly increased, without diminishing the value of F.

In the equation $F = \frac{E}{L + w}$, taken as representing the condition of a circulating force F in a determined combination of metal and acid, we have seen that F can only be increased by the diminution of L or w, or both.

We have just seen the means by which L can be diminished, and supposing that by one of these it has been reduced to $\frac{1}{n}$ its value, the equation of the voltaic pair becomes

$$F' = \frac{E}{\frac{L}{n} + w} = \frac{n\,E}{L + n\,w}.$$

With respect to w, every mode of diminishing its value, which has been before mentioned, is adopted in practice; that is, a metal (copper) is employed, the specific resistance of which is the smallest known; such a size of wire is used as can with a due regard to economy be employed, and no longer length than is actually required would, of course, ever be placed in the circuit. But there is yet another mode of reducing the resistance.

For instance, if it is desired to reduce w to $\frac{1}{n}$th its present value, it is readily done by combining n voltaic pairs in series, and applying them to circulate the current through w; the equation then stands,

$$F'' = \frac{n\,E}{n\,L + w} = \frac{E}{L + \frac{w}{n}}.$$

There are here, then, two modes of increasing the force F, and the question is, which is the greater, F' or F'', that is,

$$\frac{E}{\frac{L}{n} + w} \text{ or } \frac{E}{L + \frac{w}{n}}.$$

Their comparative values evidently depend on the respective values of L and w; for if L is greater than w, F' is greater than F''; if equal, equal; and if less, less. From this we have the following rule:—

When the resistance of the liquid stratum is greater than that of the wire, it is more advantageous to increase the size of the plates of a voltaic pair than to arrange a number in series. When the two resistances are equal, it matters not which is done; and if the resistance of the wire is greater than that of the liquid, the development of the force F is most economically obtained by placing several pairs in series.

This is a most important principle to bear in mind (as will be hereafter shown) when making an arrangement for the explosion of a series of charges: for by a simple alteration of the disposition of cells, effects can be produced which without the knowledge of this principle would be unaccountable.

The rule above made evident is supported by practice. In electro-plating, where the metallic portion of the circuit is short and ample in size, experience has taught that it is more profitable to increase the size of the pair in action. But in the explosion of charges of powder at long distances, where the metallic resistance is usually extensive, it is found more economical to arrange plates in series.

The explanation usually given for the necessity of different arrangements for the two purposes is, that in electro-plating a quantity of electricity is required, while in exploding charges intensity is essential. Intensity of heat (for this is one of the forms in which electricity can be made apparent) is a property partly dependent on the quantity of heat, and partly on the space it occupies. An increase of intensity can be obtained by putting the same quantity into less space. The same *quantity* of caloric applied to a 12 and 24 lb. shot would produce heat of various degrees of intensity. Intensity, therefore, is directly and entirely dependent on the space into which a given quantity of heat is compressed, not upon an arrangement of cells in series. It would be equally correct to say that increasing the size of a voltaic pair would increase the intensity, as to ascribe that power to the accumulation of cells in series. In fact, both these arrangements have that power, as we can imagine the same force F being made to circulate by each mode in the same combination of metals and acid—though in one case by an arrangement in series, and in the other by having one large voltaic pair—and through two wire circuits identical in their size, length, and conductibility. In the former, assuming n cells to be placed in series, $F = \frac{nE}{nL + w}$; and in the latter, w and E being of the same value as above, $F = \frac{E}{L' + w}$. And for both these values to be equal it is only necessary that L' should equal $L - \frac{n-1}{n}w$, which value is obtainable by a proportional increase of one pair of plates, as long as $\frac{n-1}{n}w$ is less than L. The same force F, then, whether caused to circulate by the conditions expressed by $\frac{E}{L' + w}$ or $\frac{nE}{nL + w}$, will exhibit the same intensity on similar parts of two identical wire circuits, and the property of producing intensity is thus shown not to be confined especially to either arrangement.

To produce any required intensity it is necessary to get the requisite quantity into the given space, and this can only be done by overcoming the obstacles to its transmission. There are two descriptions of resistance to overcome, namely, that of the connecting wire and that of the liquid, and it depends on their comparative power which it is most desirable to diminish: the former can be lessened most readily by accumulating cells in series, and the latter by increasing the size of the plates.

It is practically true that in the explosion of charges at long distances the required intensity can only be obtained by accumulating cells in series; but the reason of this is evident, namely, that in equation $F = \frac{E}{L' + w}$, even if the resistance L by the increase of the size of the plate be reduced to an insignificant value, that of w may still be too great to admit of the required quantity circulating through all parts, and then plates in series are essential to reduce the value of w, as by that means only can F now be increased.

The converse, however, is equally true, and deserves consideration. Imagine a combination of n cells arranged to overcome a resistance w, and that the number is so great that the opposition of w has been practically reduced to nothing, or the equation representing the value F standing thus—

$$F = \frac{nE}{nL + w} = \frac{E}{L + \frac{w}{n}},$$

in which $\frac{w}{n}$ is so insignificant as to admit of its being left out of the consideration, then practically $F = \frac{E}{L}$. Now, if L is so great that its resistance alone will not permit of a sufficient quantity of force circulating, then if 1000 or 10,000 cells were placed in series, we could not sensibly increase the value of F, for it could only approach, but never could equal $\frac{E}{L}$; to obtain sufficient intensity in this case it would then be essential to increase the size of each plate in the series, for by that means only could F now be augmented. These considerations are important, for they show clearly that there is a limit in each case, beyond which we can get no appreciable increase of power: in the one no further increase of the size of the plates will increase the force, unless we at the same time increase the number: in the other we may diminish the size so much as to render a large number placed in series of no value.

Returning again to equation $F = \frac{nE}{nL + w}$. It has been shown that, whatever the value of n, F *cannot equal* $\frac{E}{L}$, that is, *the electro-motive force of one pair restrained by the resistance of the inter-*

vening liquid; at the same time the combination $\frac{n E}{n L}$ has the power of circulating the force F through n times the metallic circuit which $\frac{E}{L}$ could, for $F = \frac{E}{L + w} = \frac{n E}{n L + n w}$. These two theoretical conclusions admit of the popular explanation, that in a series of cells, with plates, say of zinc and copper, each copper, while receiving excitement from the zinc of its own cell, restores to equilibrium the zinc in the next, or that to which it is metallically connected; that is, the first copper in the series tranquillizes the second zinc, the second copper the third zinc, and so on; and then there remains only the first zinc and last copper, which require to be connected to permit each to return to a state of quiescence; of course, then, any connection uniting these two, however small its resistance, cannot have so great an *amount* of electric fluid traversing it as that which one voltaic pair is able to produce, or that expressed by $\frac{E}{L}$.

At the same time, as Ohm has shown that the quantity of electric fluid travelling by two paths to the same destination will proceed by each in quantities varying in the inverse ratio of their powers of resistance, let us imagine the quantity at the last copper plate in the series desirous to return to the first zinc, and that the zinc and copper is metallically connected, bearing also in mind that this zinc and copper are connected by another means, that is, by the alternation of metals and acid solutions, both conductors intervening between them, so that there are here two paths by which equilibrium can be restored; and now if we suppose, first, the metallic resistance insuperable, the whole of the electricity will return by the liquid; if we suppose the liquid resistance to be insuperable, tranquillity will be restored wholly by means of the metallic road. But in reality, as neither resistance is actually insurmountable, the fluid does return by both roads in the inverse ratio of their resisting powers. Conceive, then, one voltaic pair with the circuit closed by a wire of any given length. In this position a certain amount of electric force is proceeding from the copper to the zinc by the wire, the remainder returning by the liquid, the proportion depending on the resisting powers of each; if, then, we increase the resistance of the liquid portion n times, we can proportionally increase that of the metallic portion without altering the absolute quantity proceeding by each path. In a combination of n cells the former is done, and then we are enabled to do the latter. When n cells are used in series, n times the resistance is opposed to the return of the electric fluid at the last plate by the liquid to the first, for it has to traverse n thicknesses of solution and n pairs of metallic plates, and so we can add on n times as much metallic wire resistance without diminishing the quantity, thereby circulating below that which would circulate through the original length, were but one voltaic pair to be employed.

This passage is not perhaps quite clear, as it would imply that an increase of the liquid resistance, taken by itself, would allow an augmentation of the wire resistance also. At page 538 the formula explains it, as it is shown that $F = \frac{E}{L + w} = \frac{n E}{n L + n w}$; $\frac{E}{L + w}$ representing the conditions of a single pair, and $\frac{n E}{n L + n w}$ that of a series of n pairs, in which L having been increased n times, w has also been increased in the same proportion; but the numerator or electromotive force has been likewise increased n times.

Proceeding on the principles thus developed by Ohm's theory to inquire into the power of every description of battery, it will, we hope, be clear from what has been said that it was in the first place necessary to ascertain the comparative value of L and w in the equation $F = \frac{E}{L + w}$ before it could be decided whether the force F would be most economically produced; and secondly, the comparative value of E to show the relative electro-motive energies of the several known combinations.

Before proceeding to detail the experimental results which determined the choice of the motive power or description of battery for military purposes, we may enumerate those that have been submitted to examination, namely:—

Wollaston's—Zinc and copper and dilute sulphuric acid, and its modifications of zinc and iron, and copper and iron.

Smee's—Zinc, platinized silver, and dilute sulphuric acid.

Grove's—Zinc and dilute sulphuric acid, platinum with strong nitric acid.

Daniell's—Zinc and copper, with dilute sulphuric acid and sulphate of copper.

Dalgleish's—Zinc, platinum, and nitric acid.

McCallan's batteries, of which there are several varieties.

These several batteries can be classified under two heads—those in which an evolution of gas takes place on completing the circuit, and those in which, for the attainment of constancy, the gas is absorbed by a chemical process. To the former class belong Wollaston's and its modifications, Smee's, and Dalgleish's; and to the latter, Daniell's, Grove's, and McCallan's.

The advantages of the first class consist in the simplicity of the arrangements, the use of but one acid, the necessity for porous cells being thus avoided; while the second has the advantage of producing greater constancy by a chemical arrangement, though at the expense of simplicity.

Wollaston's, Smee's, Daniell's, and Grove's batteries have been for some time before the scientific world, and are well known. McCallan has organized several combinations of metals and acids which require notice. In one, cast iron is simply substituted as the negative metal for the platinum of Grove's; in other forms he uses successively platinized iron, platinized lead, chromed iron, chromed lead. He also varies the exciting solutions. Now he employs concentrated nitric and doubly-rectified sulphuric acid in contact with the iron; then, again, this solution is

modified by mixing four parts of sulphuric acid, two of nitric, and two of a saturated solution of nitre together. If, in this latter mixture, nitric acid is dispensed with, its place must be supplied by an addition of the nitric solution, which, he states, need not be saturated. He also finds that nitrate of soda could be substituted for nitrate of potash, though with a loss of power to be repaid by cheapness of material.

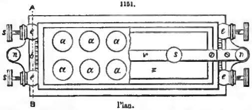
Platinized or chromed cast iron answers as well as platinized lead, and cast iron without being chromed appears to act as well as platinum.

After weighing well the relative qualities of lead and cast iron, McCallan prefers the latter, principally because it does not require platinizing.

From these remarks it seems just to infer that cast iron not platinized—that is, plain—was, on the whole, better than platinized lead, platinized iron, or chromed iron; and if this is the case in the laboratory, it will be much more so in the field, for the platinizing process will, owing to the destruction of the iron, require to be frequently repeated, entailing much expense and trouble, and requiring scientific knowledge and practice. It was only necessary then to test the merit of the substitution of cast iron for the platinum in Grove's, and the use respectively of nitric and sulphuric acid mixed, concentrated nitric and sulphuric acid mixed, and concentrated nitric acid alone, when applied to produce voltaic action. These trials have been made.

The battery made by Dalgleish, of the Ordnance Survey Office, Dublin, deserves particular notice. He employs zinc and platinum for the metals, and strong nitric acid, though it should not be concentrated, for the solution. Platinum cups containing nitric acid have suspended over them, attached to a bar, cylinders of zinc, which are kept from the influence of the acid by strong elastic bands. At the moment the voltaic action is required, a pressure on the bar immerses the zinc, and at the same time, by an ingenious arrangement, completes the connection of the several cells. An action ensues, and the desired effect being produced, the removal of the hand allows the elastic bands to withdraw the zinc cylinders, and yet to keep them suspended over their respective cups from further destruction. See Figs. 1151 to 1153.

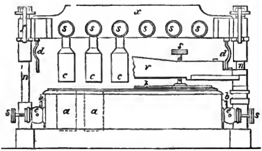
1151.



Plan.

Reference:—*a a*, Platinum cylinders in metallic communication with the platinum connectors *b b*. *c c*, Zinc rods in communication with the platinum connectors *d d*. When in action *d d* press lightly on *b b*, thus connecting each zinc rod with its corresponding platinum cylinder.

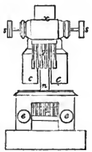
1152.



Elevation.

Reference:—The right-hand zinc rods are omitted to show more clearly the mode of closing the cylinders with the lid *z*, when not in use. *f f*, Straps of india-rubber, which are intended to raise the bar *x* when pressure is removed, so as to stop the action.

1153.



Section on A B, with portions of the battery in elevation.

Reference:—*e e*, Poles of the battery. *s s*, Screws. *n n*, Pillars on which the bar *x* slides.

Though this battery is classed with those in which an evolution of gas occurs, they can by no means compare with it in energy. Its electro-motive force is very great; nor can we by description do justice to the ingenuity of the arrangement by which the zinc cylinders are kept out of the acid till their destruction is necessary; at the proper moment the pressure of the hand immerses them, and simultaneously makes the connection of the several cells.

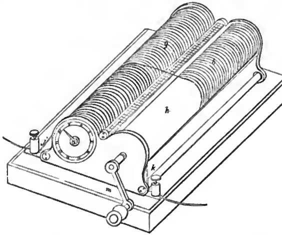
With respect to Wollaston's battery of zinc and copper, and the modifications of it before mentioned, we did not submit them to any detailed examination, for we believe it is well known and generally acknowledged that Smee's principle is superior to them in *every* way. Having satisfied himself of the truth of this general opinion, Ward tested more carefully the power of a Smee, and the result will show how inadequate such an arrangement is for the intense and constant heat required for explosions of powder.

The plan pursued in the inquiry into the merits, or productive values, of these several forms of battery, was to ascertain first the most advantageous size and arrangement of plates to cause the circulation of the required amount of force in each, and then to select the one best for use in the field.

The principle on which Ward proceeded to obtain these values was by introducing variable resistances into the circuit, and bringing the force of the current circulating in each case to an equality; then, by equating the two expressions obtained, we can arrive at the electro-motive force or resistance of the liquid, according to the conditions of the experiment.

To apply the principles mentioned, it is necessary to have the means of varying the interposed resistance gradually between any required limits; and the instrument employed was a Rheostat, Fig. 1154.

1154.



The following is a description of it:—*g* is a cylinder of wood with brass termination, and *h* a cylinder of brass, both of the same diameter, and having their axes parallel to each other. On the wood cylinder a spiral groove is cut, and at one of its extremities is attached one end of a long copper wire of small diameter, which, when coiled round the wood cylinder, fills the entire groove, and is fixed at its other end to the extremity of the brass cylinder. The two springs *j* and *k*, pressing one against the brass terminal of the wood cylinder, and the other against the brass cylinder *h*, are connected with two binding screws for the purpose of receiving the wires of the circuit. The movable handle *m* is for turning the cylinders on their axes; when it is attached to the cylinder *h*, and is turned to the right, the wire is uncoiled from the wood cylinder, and coiled on the brass cylinder; but when it is applied to the cylinder *g*, and turned to the left, the reverse is effected. The coils on the wood cylinder being insulated and kept separate from each other by the groove, the current passes through the entire length of wire coiled on that cylinder; but the coils on the brass cylinder not being insulated, the current passes immediately from the point of the wire which is in contact with the cylinder to the spring *k*. The effective part of the length of the wire is therefore the variable portion which is on the wood cylinder.

A scale is fixed to measure the number of coils unwound, and the fractions of a coil are determined by an index which is fixed to the axis of one of the cylinders, and points to the divisions of a graduated scale.

The instrument employed was made on the same principle, though of larger dimensions, as more suitable to the inquiry in view. The cylinders were 10 in. long, and exactly 10 in. in circumference, the wire employed being about ·045 in. diameter, and weighing about 53 grains a yard. The wood cylinder when covered held 190 turns of such wire, or 52¾ yds.; and it was assumed as the standard measure of resistance, estimating and expressing all other resistances in terms of this wire.

Some mode was requisite by which the force of the current circulating could be measured. A delicate astatic galvanometer first occurred to Ward as suitable for the purpose; but he found that, though well adapted for the measurement of feeble currents in circulation, it was not so suitable for measuring those of such great energy as are required for the purpose of exploding

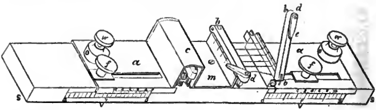
powder. It seemed that the resistance of the liquid stratum and the electro-motive forces were, in some forms of battery, dependent in a degree on the amount of electric current in circulation, or when the quantity was so minute as to be accurately measured by a galvanometer the value of L was less than when a more energetic current was passing. On the other hand, when a sufficiently strong current was circulating, the deflection of the galvanometer needle was so great, that small variations in the extent of the circuit produced no effect on the variation of the needle. Frequent changes were also apparent in the magnetic intensity of the needle when acted on by strong currents, so that two equal degrees of variation could not be taken as indications of the same amount of circulating force. It was therefore no easy matter to ascertain when a current sufficiently energetic for the object of the inquiry was in circulation.

With an intention, then, of ascertaining the amount of resistance and electro-motive force in every form of battery, when a current of sufficient energy for exploding powder was circulating, and at the same time to have a certain indication that such was the condition under which he was making the experiment, Ward adopted the following plan. In some part of the metallic circuit he placed a thin platinum wire, ⅛th of an inch long, weighing 1·65 grain a yard. Gradually varying the metallic resistance, he then ascertained the amount at which the small wire would just melt. As the same degree of heat would always be necessary to fuse the same length and thickness of platinum wire, and as that could only be obtained by the same force of current passing uniformly through all parts of the circuit, and, moreover, as the fusion of this wire would readily ignite surrounding powder, he thus obtained a galvanometer which, at one view, gave all the information required.

It was an easy matter to design an instrument for holding the wire, or any number of wires, if required. Ward had one constructed, which also permitted of two wires being placed in successive parts of the circuit, or, if necessary, of two sets of six, the wires of each set being arranged side by side. (The reason for both these arrangements will afterwards appear.) They were held firmly between parallel brass plates; and by means of screws, clamps, and a graduated scale with a vernier attached, any length, from the smallest imaginable to 1½ in., could be introduced in the circuits for the purpose of experiment. As it is an instrument for measuring energetic currents, it may be called an intensity galvanometer.

Fig. 1155 represents this instrument. *s s* is a wooden stand, resembling a flat ruler, having two graduated scales *v v* of inches and tenths of inches corresponding to the verniers on the bent down edges of the brass slides *a a*. In the figure the right slide is represented as drawn back, and it will be observed that it carries with it a vertical brass transverse plate, provided with slits for the reception of the platinum wires, which are then kept firm by the capping bar *b d*, here represented open, but which turns on a hinge at *b*, and is secured firmly to the plate when down by the lever-catch represented at *e d*. The other ends of the wires are received in slits of a similar upright piece, which forms part of the centre plate *m*, which is attached permanently by screws to the wooden stand. This upright piece has also a lid *p d*, which is here represented as

1155.



closed on the wires. The left slide *a* consists of the same parts, but is here shown as closed in to the central upright piece on that side; the two uprights being covered by the cap C, which keeps up a metallic connection between the left and right slides, just as the platinum wires do on the other side. By removing the cap C the left slide becomes movable to the left, and wires can be inserted between the upright of the slide and that of the central plate, just as is exhibited in respect to the right-hand slide. *f f* are clamping screws to secure the slides in any required position. *w w* are screws for receiving the connecting wires of the battery. When it is only intended to use a single wire or a set of wires, from two to six, arranged side by side, the cap C must be down on one side, either the right or the left, as here represented; but when it is wished to use two distinct wires successively in line, or two sets of wires in succession, the cap C must be removed. The instrument may be made to complete the circuit, if necessary, without the platinum wires, by closing up the slide on the right as on the left side, and covering the uprights by another cap similar to C.

As before stated, there were barely 53 yds. of standard wire on the rheostat, but it was generally necessary to introduce much greater resistance than this. The means of doing so were easily obtainable, for having on hand about two miles of thin copper wire, varying from 160 to 250 grains a yard, covered with gutta-percha, in lengths varying from 75 yds. to half-a-mile, it was only necessary to ascertain the resisting power of these in terms of the standard wire, and by Wheatstone's instrument this was readily done. Thus with a piece 75 yds. long, taking a Grove's battery (though any constant battery would do equally well), Ward found that three of its cells were capable of fusing the thin platinum wire before men-

tioned, when 119¼ turns of the standard wire coiled on the wood cylinder of the rheostat wire were included in the circuit; and the same three cells fused the same length of wire when a coil of wire of *another description* 75 yds. long, together with 68¾ turns of rheostat wire, composed the circuit. Now, three cells acting in series are expressed by $\frac{3\,E}{3\,L}$, that is, three electro-motive forces divided by three liquid resistances, if L represent the resistance of the liquid of one cell. The other resistances are in the first experiment composed of 119¼ turns of standard wire, and the platinum wire, the amount of whose resistance we may call p: in the second, of 75 yds. of coil, 68¾ turns of standard wire, and the platinum wire p. Under each condition of experiment the same amount of force was capable of circulating; calling this F, we have

$$F = \frac{3\,E}{3\,L + 119\tfrac{1}{4} + p} = \frac{3\,E}{3\,L + 68\tfrac{3}{4} + 75 \text{ yds.} + p}.$$

By which we obtain 75 yds. = 51 turns; or the resistance opposed by the 75 yds. of coil was equivalent to that of 51 turns of standard wire, and whenever this portion was introduced into the circuit it was considered equivalent to 51 turns of standard wire. Again, with a piece of greater length, eighteen cells of another battery were capable of fusing the platinum wire, the current passing through an equivalent of 868¾ turns of standard measure, and when a piece 550 yds. long was introduced, the same result could be produced through but 88½ turns. The 550 yds. piece was then = 868¾ − 88½ = 780¼ turns of standard wire: and to show the degree of accuracy attainable, each result (namely, 868¾ and 88½) is the mean of eight observations; the first eight observations differing from the mean 868¾ as follows—

¼, 2¾, 2¼, 1¾, 2¼, ¾, 3¾, 4¼;

and the second eight from the mean 88½ as under—

5½, 6½, 2½, 2½, ½, 4½, 2½, 1½.

The probable error of the mean difference resulting from these sixteen observations does not exceed 1·15 turn: that of a single pair of observations being within 3·3 turns. The galvanometer is, however, capable of measuring to a still greater degree of accuracy, if necessary. The above observations were made with a battery not particularly suitable to the purpose, and with less than the usual degree of care, in a period of less than a quarter of an hour; the coil in question not being required for the subsequent experimental inquiry. The instrument admits of a repetition of from 40 to 60 observations an hour with ease, and thus, in a short time, it would be easy to obtain a result free from any but an almost inappreciable error. In a similar manner the resistance of any length of wire could be reduced to a standard measure; and as the wires were covered with gutta-percha, Ward was able to arrange them in coils round the table on which the battery stood, introducing such as were required by the nature of the experiment.

As the thin platinum wire before mentioned necessarily formed part of the circuit in *every experiment*, it was requisite to ascertain its resistance in terms of standard measure. This was done by first introducing one, and then two such wires, all of the same length, in different portions of the circuit (for which, as has been described, the galvanometer was adopted), and producing a fusion in each case *by the same power of battery*. The amount of standard resistance or length of standard wire which had to be taken out in the second case to produce fusion, was equivalent to the resistance of one platinum wire. This was found, by the mean of six pairs of observations, to be 60¾ turns. The probable error of this result being = 1 turn, and that of one pair of observations = 2·3 turns, is equivalent—as the wire is but ·375 in. long—to ·00618 in. in the former case, and to ·0142 in the latter.

A ready mode of checking the correctness of this result is always at hand: it is as follows:—Find the utmost length in standard measure of the metallic circuit (not including that of the platinum wire) which will admit of any even number of cells in series, say twelve, fusing that wire. Ascertain the same with each half, or six of those cells. The sum of the circuits of the two sixes deducted from that of the twelve will give the standard resistance of platinum wire. This will be a true result, subject of course to corrections for errors of observation, however irregularly the cells may be working *inter se*; and a reference to the formula will easily explain the rule.

It might be supposed that the resistance of these several wires would be ascertainable by the formula $w = \frac{s\,l}{a}$, when the specific resistance, the length, and the area of the section are known; or if they are all of copper, the specific resistance being the same, that the length divided by the weight a yard should give the comparative resistance; but an approximate value can only be obtained by such measures. A small variation in the description of copper from which the wire is manufactured would affect the value of s, and the difficulty of obtaining in wires of small diameter a correct value for a, or, what is its equivalent, the difficulty of obtaining a long wire of a uniform weight a yard, would increase the probable error of the true result. For instance, several portions of the same wire weighed 249·5, 233·5, 228·6 grains a yard, as ascertained by a delicate balance turning to $\frac{1}{100}$ of a grain, thus denoting an irregularity due either to the manufacture or to the quality of the copper.

It is therefore fortunate that Wheatstone's rheostat furnishes such a ready, as well as practical, mode of ascertaining the degree of resistance of all descriptions of wire *without a knowledge of any of the factors of the equation* $w = \frac{s\,l}{a}$.

The amount of error into which we may be led by determining the resistance from calculation instead of by experiment may be seen from the following Table, in which that practically ascer-

tained and that calculated, each in terms of wire weighing 53 grains a yard, are placed side by side:—

Actual length of Wire, in Yards.	Weight per Yard, in Grains.	Calculated Resistance in turns of Rheostat.	Actual Resistance by Experiment in turns of Rheostat.	Percentage of Error in Calculation.	Percentage of Probable Error in ascertained Resistances.
75	233·22	61·3	51	+ 16·8	0·58
125	228·66	104·3	83¾	+ 19·7	0·53
245	233·5	200·2	172¾	+ 13·7	0·46
495	249·5	378·5	322⅛	+ 14·8	0·34
280	166·2	321·4	401⅝	− 24·9	0·41

Thus the first four lengths (which, as before stated, are portions of one original piece, and were therefore probably manufactured from one description of copper) are tolerably consistent among themselves, though differing on an average by more than 15 per cent. *plus* from the standard, whereas the last piece shows a *minus* error of nearly 25 per cent., making an aggregate error between the two descriptions of copper wire shown in the Table of about 40 per cent.

Here, then, is made apparent one of the probable sources of failure in demolition by voltaic agency. The different diameters of the pieces of 495 yds. and of 280 yds., though apparent on *close* examination, would not strike a casual observer; in fact they were purchased from the Gutta-percha Company as one description of wire, yet the resistance of the *shorter* lengths as compared with the *longer* is as 402 to 323! If, then, calculating on the experimental results obtained from the former, the same length of the latter wire had been used in any preposed demolition, the probable result would have been total failure.

The last column shows the prebable error in the ascertained resistance, which averages under one-half per cent. These results are more than sufficiently accurate for the purpose of the inquiry, though by no means so near as it would be easily possible to attain, since it is within the compass of an easy day's work to ascertain the resistance of all these lengths to within $\frac{1}{10}$th per cent. of probable error, and even to eliminate error altogether.

It was easy now to obtain the value of L or the resistance of the liquid stratum in any battery, as well as the proportional value of any electro-motive force. The experimental results with each battery examined now follow, being prefaced with a description of the size and mechanical arrangement of each. Ward had, for the commencement of the investigation, that battery of Grove's construction which was employed in the demolition of Seaford cliff in 1850. It was supplied to the Engineer Department at Portsmouth as the best form and description of voltaic implement known for the purpose, and therefore deserves a description to show how much such an instrument is capable of modification, when required solely for blasting purposes.

The battery consisted of ten cells, in each of which was suspended one plate of platinum, with two of zinc facing it, one on each side, at a distance of ¾ of an inch: the exciting solution being dilute sulphuric acid for the zinc in the proportion of 1 of acid to 8 of water, and strong nitric acid for the platinum, the two acids being separated by a porous earthenware diaphragm; the plates in action in each were two 9" × 7" of zinc, and one 6" × 6" of platinum; each cell requiring 2¼ pints of dilute sulphuric acid, and ¾ of a pint of nitric acid. Its weight when charged was 168 lbs., of which 40 lbs. was due to solution and 44 lbs. to zinc plates.

Each cell then had the power of circulating the standard force required, that is, a force capable of fusing thin wire, through a resistance of 66¼ turns standard measure.

It was evident, on first sight of the instrument, that this battery would admit of considerable reduction, if the principles of Ohm's theory were correct; and that if the distance between zinc and platinum was reduced from ¾ to ⅜ of an inch, one-half the weight of zinc (= 22 lbs.) and a corresponding bulk of acid could be dispensed with, without lessening in any degree the power of each cell. With this consideration in view, and also wishing to compare an arrangement on Grove's principle with one of Smee's batteries, Ward had one of the former constructed with twelve cells, two zinc plates 4" × 2" being in action in each cell, one on each side of a platinum plate 4" × 4" and at a distance from it of about ⅜ of an inch. The experimenter also had the platinum plates platinized, the original object of which was to work this identical battery as a Smee, by dispensing with the porous cells and nitric acid; but thinking afterwards that this might appear to some as hardly a fair trial of Smee's arrangement, Ward abandoned that idea, and used these platinized platina plates in the Grove's arrangement only. It will be seen subsequently that platinized platina opposed to zinc gives a stronger arrangement than platinum only—a fact which was first noticed by McCallan.

The investigation was intended to find the power of the several voltaic combinations when excited by ordinary agents, that is, those which might readily be obtained: our author did not enter into an inquiry, except on special occasions which will be particularly noticed, as to the degree of power attainable by the use of concentrated nitric acid, doubly-rectified sulphuric acid, or such reagents as are difficult or expensive to procure, or dangerous to handle; but confined himself to the task of ascertaining the power attainable from ordinary, or what are termed commercial, acids, which do not emit fumes destructive to health.

The rule for ascertaining the merits of any voltaic combination is this. Arranging any number of cells in series, ascertain the metallic resistance that can be comprised in the circuit which will permit one platinum wire to be fused. With the same number in series, ascertain the extent of circuit which will admit of two platinum wires placed side by side in the galvanometer being fused; and these two experimental results may be obtained in five minutes at any time in the

field as well as in the laboratory, with instruments which should always accompany the battery, by a single observation of each result with a probable error not exceeding two turns; whilst by a repetition of observations, all appreciable error could, of course, be eliminated. In making these trials, it is not necessary that the operator should have any knowledge of the metals or acids of which the voltaic arrangement is constituted. The experiment will show him at once if the battery is to be trusted, and to what extent, and, if any disarrangement has occurred, how many cells to add to overcome the defect: indeed, the constancy and duration of the heat made apparent on the wire is at once an infallible and ready test of the value of the battery for explosive purposes.

The demonstration is as follows:—Taking n cells in a battery whose electro-motive force is E, and resistance of liquid L, suppose a metallic resistance w to be the extreme that can be interposed and yet enable a force to circulate that will cause the platinum wire to be fused; call this force F, then the equation stands $F = \dfrac{n\,E}{n\,L + w}$. Now, if the extreme metallic resistance, which we will call w', is ascertained which admits two identical wires, placed side by side, to be fused, it is evident that the same force F must be passing along each wire at that moment, or a force of 2 F along both together; and as the same quantity of electric fluid must be passing through every part of the circuit, the equation representing the conditions under which the battery is working will be expressed by $2\,F = \dfrac{n\,E}{n\,L + w'}$. Now, as the numerator in both these expressions is the same, for in both experiments the same number of cells are used, the denominator in the last must be one-half of that of the first, or $n\,L + w' = \tfrac{1}{2}(n\,L + w)$ $\therefore L = \dfrac{w - 2\,w'}{n}$. Thus the average resistance of n liquid strata, or n L can be obtained. The use of this value of L will be better understood when we come to consider the other numerical values in each case.

Again, suppose we have two separate combinations of battery, say a Smee and a Grove arrangement, of which it is desired to determine the comparative value of the electro-motive forces: let the electro-motive force be E and E', liquid resistance L and L', and the quantity of metallic circuit that each will bear when n cells are combined, and yet permit the standard force, which we will in future call a force F, to circulate, be w and w'. Let the amounts w and w' require an increase or diminution $= a$ and a' of metallic resistance when a force F' is required to circulate. We then have in the first case,

$$\overset{\text{SMEE.}}{\frac{n\,E}{n\,L + w}} = F = \overset{\text{GROVE.}}{\frac{n\,E'}{n\,L' + w'}}, \text{ and in the second } \overset{\text{SMEE.}}{\frac{n\,E}{n\,L + w \pm a}} = F' = \overset{\text{GROVE.}}{\frac{n\,E'}{n\,L' + w' \pm a'}};$$

then of course E : E' as the sums of the respective denominators in each case, but they are also as the differences of the denominators of their respective fractions, that is to say, as a to a', or E : E' :: a : a'.

In all these observations the forces F and F' have been in the ratio of 2 to 1, to simplify the calculation; and the equations under the conditions became

$$F = \frac{12\,E}{12\,L + w};\ F' = 2\,F = \frac{12\,E}{12\,L + w \pm a},$$

which being reduced, for the purpose of determining L or the liquid resistance, gave $12\,L = w - 2(w \pm a)$: and on these principles Ward took the observations that follow, the number of cells in series in all cases being twelve.

With the Grove's having plates, 4" × 4", of zinc, and platinum in action in each cell,

1. The metallic resistance interposable for 12 cells, when one wire was fused .. .. } or $w = 775\tfrac{1}{2}$ turns.
2. With two wires .. .. or $w - a = 350\tfrac{1}{2}$ „

$\therefore 12\,L = 775\tfrac{1}{2} - 701 = 74{\cdot}5$ turns; the probable error in this value of 12 L, as calculated from the nature of the observations, is $= 1{\cdot}7$ turn; that of $775\tfrac{1}{2}$ turns, similarly calculated, is equal to 2 turns.

The electro-motive force of this battery as compared with any other would be the difference of these two observations in each case, that is to say, the difference of the denominators of the equations F and F', as before stated. In the present case this is $775\tfrac{1}{2} - 350\tfrac{1}{2} = 425$, having a probable error of 1·6.

The duration of the power of this battery, or its constancy, as it is called, is deserving of notice. The results just given show its energy about an hour after charging, at which time, the porous cells being well saturated, it may be considered to have been at its maximum. During the day it was experimented with sufficiently to fire 300 charges, and at the end of seven hours the experiments above described were repeated in the same order. No. 1 gave $753\tfrac{1}{4}$ turns; No. 2, $332\tfrac{3}{4}$, from which $12\,L = 88$, and comparative value of $E = 420\tfrac{1}{2}$. Thus the resistance of the liquid had, as regards itself, increased 18 per cent., and the electro-motive force 1 per cent.; but the two together had reduced the available energy of the battery from $775\tfrac{1}{2}$ to $753\tfrac{1}{4}$, or not 3 per cent. This constancy is readily attainable by carefully amalgamating the zinc plates before charging, an operation occupying a few minutes; and it has been found on this as well as on other occasions that the battery will continue sufficiently constant for all practical purposes for a period of twelve hours. The small loss of power noticeable here is probably owing to the fact that it was always Ward's custom in charging the several batteries to mix the sulphuric acid and water immediately before filling the cells; this, as is well known, raises the temperature of the mixture above that previously sensible in either of the liquids, and as the temperature is heightened the conducting power of the

solution is increased; but this power diminishes as the solution cools, which it gradually does. On the present occasion sulphuric acid and water, each at 40° Fahrenheit, when mixed in the proportion of one measure of acid to eight of water, gave a resulting temperature of about 70°.

When this battery is in its full strength, the amount of resistance commanded by 12 cells, that is, the amount of metallic resistance which can be added to the circuit for each cell in series without diminishing the value of the circulating force below the standard necessary for fusion, is = $775\frac{1}{3}$ turns for the 12, or $64\frac{3}{5}$ for one cell; but it will be remembered that the power of one cell in the large Grove did not exceed $66\frac{1}{3}$ turns, so that this small difference is the only loss a cell by reducing the battery. In respect to the gain, the quantity of nitric acid to charge each cell has been diminished from $\frac{2}{3}$ to $\frac{1}{8}$ of a pint, and the dilute sulphuric acid from $2\frac{2}{3}$ to $\frac{1}{4}$ of a pint. These two alone diminish the cost of charging 10 cells from 7*s.* 9*d.* to 2*s.*; but as this acid lasts only 12 hours, while the others are available for 24, the comparative cost should stand as 7*s.* 9*d.* to 4*s.* The weight of 10 cells of this battery when charged was only 27 lbs., while that of the large one was 168 lbs. The cost of construction was less than one-half, and the cubical contents less than $\frac{1}{8}$. So that while but $1\frac{3}{5}$ per cent. of power a cell has been lost, the gain has been 50 per cent. in prime cost, the same in working, 600 per cent. in weight, and 700 per cent. in bulk.

Referring back, let us substitute in the equation $F = \frac{a\,E}{a\,L + w}$, the value of $a = 12$, $a\,L = 74\frac{1}{3}$, and $w = 775\frac{1}{3}$, and we have $F = \frac{12\,E}{74\frac{1}{3} + 775\frac{1}{3}} = \frac{E}{6\frac{7}{36} + 64\frac{11}{18}} = \frac{E}{70\frac{5}{6}}$, in which $70\frac{5}{6}$ represents the utmost amount of resistance in standard measure that this principle of battery will bear a cell, without reducing the amount of circulating force below the force capable of fusing the thin wire, that is the force F, and in which $\frac{E}{5\frac{7}{36} + 64\frac{11}{18}}$ represents how this total resistance is apportioned between the liquid and metallic circuit, in this particular sized battery. But the same resulting force could be obtained by a battery working under any of the following conditions, namely,—

$$F = \frac{E}{24\frac{5}{6} + 46} = \frac{E}{70\frac{5}{6}}, \qquad [1]$$

$$\text{or} \qquad = \frac{E}{35\frac{5}{12} + 35\frac{5}{12}} = \frac{E}{70\frac{5}{6}}, \qquad [2]$$

$$\text{or} \qquad = \frac{E}{70\frac{5}{6} + 0} = \frac{E}{70\frac{5}{6}}. \qquad [3]$$

The first of these can be produced by a diminution of the size of the plates from 4″ × 4″ of surface in action in each cell to 2″ × 2″; and as this reduction of size would not diminish the power a cell 30 per cent., or from $64\frac{1}{3}$ to 46, while it might reasonably be expected that the expense of charging, weight, bulk, and cost of battery would be diminished at least 100 per cent., this modified form is evidently preferable.

No. 2 is, theoretically speaking, the most economical form under which any principle of battery can work for the circulation of the force required, which in this case is to fuse the particular platinum wire that we have been using, that is, when the liquid resistance of each cell is equal to its available energy; and in a Grove's combination the expression represents plates about 1·66 in. square in each cell.

The third expression represents a battery working under such conditions that if 1000 cells were placed in series they would not have the power of circulating the force F through a metallic circuit of 1 ft.

Theoretically speaking, No. 2 is the most economical form of battery; but other considerations forbid its adoption. To obtain the power, $35\frac{5}{12}$ the cell indicated by the equation, each compartment must be carefully filled to the top, as failing to do this by a quarter of an inch would sensibly diminish the power a cell. Any deterioration in the strength of acid employed would have the same effect, and the whole quantity employed being so small, it would deteriorate soon after the battery was charged. It will be seen that the acids used in the Grove, of which the zinc surfaces in action were 4″ × 4″ in each cell, were available for but 12 hours, while that in the larger size was equally so for 24 hours. Reasoning from this, it could then hardly be expected that the small battery represented by equation No. 2 would remain efficient for one hour, or work economically for one quarter of an hour.

One more condition of this equation deserves notice, namely, $F = \frac{E}{0 + 70\frac{5}{6}}$. This cannot practically be attained by any construction, for the liquid resistance must be an absolute quantity; but it shows the important fact that *however large* the plates of a Grove's combination, such as the one we have been considering, are made, the force F could not circulate if in *each* cell was developed resistance equivalent to $70\frac{5}{6}$ turns, while *two* cells 2″ × 2″ can bear a resistance more than equal to this, and yet circulate the required force with ease; in other words, that for the circulation of the force we require two pairs of plates in series, each 2″ × 2″ in surface, which are more than equivalent in force to one plate even a mile square.

No. 1 arrangement having then been decided on as the best, a battery exactly similar to the former was made, but having zinc plates 2″ × 1″ overlapping platinum 2″ × 2″; the former facing the latter on each side, and thus giving a surface of each metal 2″ × 2″ in action in each compartment. This diminution in size permitted the zincs to be brought somewhat nearer; and, instead of being $\frac{3}{8}$ of an in. from the platinum, they were $\frac{5}{16}$.

The experiments Nos. 1 and 2 were made with this battery, giving the following results as the mean of eight observations of each: No. 1 = $571\frac{11}{18}$; No. 2 = $162\frac{1}{12}$; from which the comparative

value of $E = 409\frac{4}{5}$, and the resistance of $12\ L = 245\frac{5}{8}$: the probable error in each result being 1·5. The diminution of the comparative value of E from 425 to $409\frac{4}{5}$ is attributable to the platinized platinum being used in the former case, while ordinary sheet platinum was employed in this, and not to a diminution of size, which does not influence E. The sum of the resistances of the liquid in twelve cells had increased from 74·5 to $245\frac{5}{8}$.

Now, remembering that the plates had been reduced to $\frac{1}{4}$ the size, but had been brought nearer in the proportion of 5 to 6, calculation from the first result would give the second

$$= \frac{74\cdot 5 \times 4 \times 5}{6} = 248\tfrac{1}{3},$$

whilst experiment gives $245\frac{5}{8}$. Assuming the value of $12\ L = 245\frac{5}{8}$ or $L = 20\cdot 47$, and that of $w = \frac{571\frac{4}{5}}{12} = 47\cdot 65$; the expression $F = \frac{E}{L + w}$ stands $\frac{E}{20\cdot 47 + 47\cdot 65} = \frac{E}{68\cdot 12}$, showing that when the platinum is *not platinized* a Grove will bear a resistance of but 68 turns of standard measure instead of nearly 71, as before, to each cell.

Referring back to the largest Grove, namely, that with zinc plates 9″ × 7″ and platinum 6″ × 6″, we may consider the area of the mean section of the fluid on each side = $49\frac{1}{2}$″, and the plates being $\frac{3}{4}$ of an in. apart, facing the platinum on each side, the value of 12 L in this battery by calculation would be $\frac{74\cdot 5 \times 16}{49\cdot 5} = 24$ nearly, or about 2 turns a cell; and as the available energy of the battery is $66\frac{1}{2}$ turns, the condition under which the largest Grove circulates a force F is numerically expressible thus; $F = \frac{E}{2 + 66\frac{1}{2}} = \frac{E}{68\frac{1}{2}}$, which, admitting experimental error, is the same expression as that obtained from plates but 2″ square; thus showing that increasing the size of plates does not increase the electro-motive energy, that is the value of E, for the superior available energy of $66\frac{1}{2}$ turns in the large Grove is merely due to the diminished resistance.

This principle has been established, both by Ohm's theory and experiments, and required no further demonstration, except to bring the consideration of it to special notice as materially affecting a part of the following inquiry.

The batteries hitherto used, it will be borne in mind, were made with zinc plates *overlapping* the platinum plate, and facing it on each side. Thus the outer surface of the zincs was not directly opposed to any negative metal. To ascertain if this portion did any work, Ward carefully covered with a thick coating of sealing-wax varnish the outer surfaces, so that it was impossible they could be acted on, and then tried on a subsequent day the variation of E for 12 cells, as compared with former experiments, but he found no diminution of power. To make sure that this was not owing to any peculiarly good acid used on that day, he removed the varnish from each plate and reinserted them in the same solutions. The battery was found somewhat diminished in power, but very slightly, not more than 2 per cent., though if the outer surfaces had been acting, it ought to have *increased* in power. This was probably owing to the longer time it had been in action. These trials evidently proved that no sensible power is obtained from the outer side of a plate, or from any other surfaces that do not directly oppose each other; for had there been 3 per cent. of increase it would certainly have made itself apparent. It is not at all surprising that it should be so; for, referring to the principles of the action, the electro-motive force, that is, the affinity of the zinc and liquid for each other, depending on their nature, and not their quantity, cannot be increased; the amount of electric fluid they can supply is unlimited, and controlled solely by the resistance of the liquid to its transmission, this resistance varying directly as the distance between the plates; and hence it seems in due course that the whole of the supply should be obtained from the parts where it can be so done with the greatest facility, namely, from those which are nearest to or directly opposing the platinum.

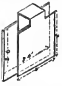
The result, however, must not be confounded with, or supposed contrary to, those obtained when the zinc, being opposed on each side by a negative metal, the battery is found to exhibit greater energy than when the copper or platinum, or whatever the negative metal may be, is on one side only; for here the zinc is directly opposed by a negative metal on both sides, and, of course, supplies electric fluid from each side, though the negative metal is, in this case, not working to the utmost advantage. The fact however made evident, to whatever cause attributable, was of great importance, as it admitted of the battery being much simplified, of dispensing with many binding-screws and of much unserviceable metal, as well as of an economy of size and weight, and an increase of power, for the plates could now be brought nearer together.

Adhering, then, to the same sized plates, a diminution of which seemed of no practical advantage, a battery was constructed with plates of zinc and platinum welded together in the simple style that zinc and copper used to be arranged in, one of each pair being in a separate cell, and the platinum immersed in nitric acid being, of course, separated from the zinc of another couple immersed in dilute sulphuric acid by the porous cell containing it and the nitric acid. A battery so made permitted the plates to be brought to an average distance of little more than $\frac{1}{16}$ of an in. from each other, and by the simple contrivance of a lid, every pair and every porous cell was kept in its place, and could be thus transmitted as ordinary baggage by rail, without extra packing or precaution. Fig. 1156 represents one of these batteries of six plates, and the connecting metallic straps are so represented as to explain the manner in which several of these batteries may be combined together; Fig. 1157 represents a single pair of plates.

Six pairs of plates so arranged occupied a box not exceeding 7″ × 4″ × 4″, substantially made for use in the field, including binding-screws and porous cells; and the reason for this arrangement of six cells in one box will be afterwards explained. The result of the fusion of one and of two wires by twelve cells, or two box batteries of this arrangement, gave on one occasion, No. 1 = 651, and No. 2 = $240\frac{3}{4}$; from which $12\ L = 169\frac{1}{2}$, and the proportional value of $E = 410\frac{1}{2}$.

On another occasion, No. 1 gave 641, and No. 2 gave $230\frac{3}{4}$, showing that the total resistance 12 L was now = $179\frac{1}{2}$, but that the value of E was unchanged; the variation in the resistance being due to the time at which the experiments were made, as the increase was probably owing to a different set of twelve having been used in each case.

1157.



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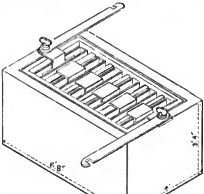


If we adopt the mean of these two, or 12 L = 174·5, L = $14\frac{1}{2}$ may fairly be taken to represent the resistance of the liquid when the battery is in its strongest action, namely, for the first three hours after it is charged. Also the electro-motive force of a Grove battery unplatinized may be represented by the numerical value 410, as on three separate occasions experiments have given it $409\frac{4}{15}$, $410\frac{1}{4}$, and $410\frac{1}{2}$, that of a platinized Grove being 425.

To ascertain how much the power of this battery diminished when left charged, the same experiments were repeated after six hours, and No. 1 was then found = $481\frac{1}{2}$, and No. 2 = $101\frac{1}{2}$; giving E = 380, and 12 L = $275\frac{1}{2}$. Thus the electro-motive force had diminished 7 per cent., and the liquid resistance had increased 35 per cent. These two circumstances combining, diminished the available energy of the battery a cell from $\frac{646}{12} = 53\frac{5}{6}$ to $\frac{484\frac{1}{2}}{12} = 40\frac{3}{8}$, or about 25 per cent.

For the first two or three hours the conditions under which the force F circulates in the battery is expressed by $F = \frac{E}{14\frac{1}{3} + 54} = \frac{E}{68\frac{1}{3}}$, which expresses that each cell commands a resistance, or has an available energy sufficient to overcome a resistance, equivalent to 54 turns of standard wire. At six hours after charging, this command had decreased to $40\frac{3}{8}$ a cell, for the battery then worked under conditions expressed by $F = \frac{E}{23 + 40\frac{3}{8}} = \frac{E}{63\frac{3}{8}}$. The denominators $68\frac{1}{3}$ and $64\frac{1}{4}$ denoting the comparative strength of the electro-motive force at the two periods.

This, then, is believed to be the most convenient form, size, and arrangement, for a Grove battery intended for the explosion of powder; for though on looking at the numerical value of $L + \frac{w}{n}$ it may seem that the size of the plates could yet be reduced, it must be borne in mind that, though a forces expressed by $\frac{E}{68\frac{1}{3}}$ and $\frac{E}{63\frac{3}{8}}$ are sufficient at their respective periods for fusing the platinum wire when in the galvanometer, a still greater force will be necessary for the same fusion when that wire is surrounded by powder. A small platinum wire, not exceeding ·0056 of an in. in diameter, in contact with any substance, must be subject to a great abstraction of heat; but how much this is Ward was not able accurately to determine, though supposing, as he believed to be the case, that about one-third is thus withdrawn, $\frac{E}{45}$ and $\frac{E}{42}$ would more nearly represent the force required to circulate, under such circumstances, to produce fusion, giving $46 - 14\frac{1}{2}$, or $31\frac{1}{2}$, and 42 − 23, or 19, as the available energy to each cell. Again, if a number of charges in a circuit are to be fired, a still greater amount of circulating force is desirable to ensure success, and overcome small differences in the lengths of the several platinum wires. Sometimes also a thicker platinum wire may be employed, which would require greater power to fuse. For all these reasons any further reduction is unadvisable.

Having thus decided that the size, form, and arrangement just described were the most convenient for a Grove battery, when required for the purposes of exploding powder, Ward proceeded to ascertain what increase of power he could obtain from it by using first concentrated nitric acid, specific gravity 1·500, and then a mixture of concentrated nitric and sulphuric acids, in equal proportions.

With the former, No. 1 experiment gave 701.
" " No. 2 " " 262.

From which 12 L was found = 177, and the comparative value of E = 439; and he therefore concluded that concentrated nitric acid, used in place of the commercial acid, increases the electro-motive energy of the battery about 7 per cent., but has no influence on the resistance of the liquid.

The mixture of concentrated nitric acid with sulphuric acid, in equal proportions, has for its object the strengthening of the former; as the sulphuric acid, from its powerful affinity for water,

withdraws that, which is essential for the preservation of nitric acid in its liquid state. A combination of the sulphuric acid with the small quantity of water it finds disengages also a very great amount of heat, and the mixture gives forth copious fumes of nitric acid, which are destructive to health; the liquid at the same time in any but practised hands being dangerous to handle. It is desirable therefore that such a mixture should never be applied in the field, or be put into unskilful hands. Its effect in giving energy to the battery was however tried, and the result was that at first, while the acid was warm, it had the effect of reducing the resistance of the liquid, but gave no appreciable increase of electro-motive force. When the whole had fallen to the ordinary surrounding temperature, all extra power had vanished. The employment of concentrated nitric acid alone gave an increase of electro-motive energy of but 7 per cent. to each cell above that when common acid was used. The price of the former is about three times that of the latter, and its fumes are deleterious, while the latter hardly emits any. Ward therefore considers it unnecessary to employ these extraordinary reagents in any case, especially when any inferiority of power can be compensated by a proportional addition of cells.

It may be as well, before leaving the Grove principle, to show how much the original battery was susceptible of improvement for our particular object, and to do this our experimenter has arranged, side by side, the expenses of keeping each charged during 24 hours, so as to be able at any time during that period to fire one charge through conducting wires weighing about 250 grains a yard, at the distance of half a mile, assuming what his experiments have shown must be about the truth, namely, that when allowance is made for the cooling effect of the powder, a power represented by $\frac{E}{46}$ will fire instantaneously one charge, with platinum wire $\frac{3}{8}''$ long, and weighing 1·66 grain a yard.

	Large.	Small.
Price of acids (used to charge)	17*s.* 6*d.*	7*s.* 6*d.*
Weight of apparatus charged	$386\frac{1}{2}$ lbs.	$36\frac{1}{2}$ lbs.
Size of apparatus	6 cub. ft.	$\frac{1}{3}$ cub. ft.
Cost of ,, ...	46 guineas	under 10*l.*

The inquiry into the power of Grove's principle of voltaic combination has been given in some detail, to show the mode of proceeding, and the conclusion to be drawn from experiment.

Bearing in mind that the size of the plates has no influence on the electro-motive force, and that any diminution of them makes itself apparent only by an increase of the resistance of the liquid reaction, it will be seen that it was easy to obtain the electro-motive energy of any particular arrangement, by simply altering the metals and exciting solutions. Thus, if cast iron was substituted for platinum, and experimental results 1 and 2 obtained, we have a complete knowledge of the electro-motive energy of one of McCallan's batteries, and also its resistance *when made of that size.* The former numerical result would stand true under any arrangement of cells and plates, and from the latter the liquid resistance of any arrangement could be deduced sufficiently near for all practical purposes.

With Daniell's battery we have but to substitute copper for platinum, and sulphuric acid and copper, in the proportions recommended by Ward, for nitric acid, and we could obtain its power under every condition, and so on with any other combination. First, with respect to Daniell's arrangement, the metals were zinc and copper; and the solutions dilute sulphuric acid, in the proportion of one of acid and eight of water for the zinc, and a saturated solution of sulphate of copper in dilute sulphuric acid, of the same strength, with the copper; the two solutions being kept apart by a porous diaphragm, whilst the temperature and conditions under which the trials were made were similar to those to which Grove's principle had been subjected.

The electro-motive force as compared with Grove's was as 235 to 410, though, as these results were somewhat hastily obtained, we do not submit them as wholly accurate; and the resistance of the liquid of 12 cells 2″ × 2″ was $242\frac{2}{3}$ turns, Grove's having been found to have $174\frac{1}{3}$ at the first hour, and $275\frac{1}{4}$ at the end of six hours.

Daniell's battery has the advantage of greater constancy, its liquid resistance, while the sulphate of copper is kept saturated, remaining the same at the same temperature. On the other hand, difference of temperature has considerable influence on the success of the battery, owing in a great measure to the variation of the resistance of the liquid; the dilute acid at a high temperature taking up more sulphate, which, as the mixture cools, crystallizes in the pores of the diaphragm, and thus increases the resistance and diminishes the energy of the battery.

Ward did not test what difference is due to changes of temperature, for a Daniell's arrangement being more complicated than Grove's, it was but necessary to compare them under ordinary conditions of temperature to determine their relative merits in the field, where means for raising an artificial heat cannot be generally accessible.

Grove's battery is not so influenced by changes of temperature; that indicated by 50° Fahr. being in all cases sufficient, and superior to this can always be obtained by mixing the sulphuric acid and water just previous to charging the cells.

A trial was made to form an idea what difference of power would result if a saturated solution of sulphate of copper in water was used in preference to the same in dilute sulphuric acid. The electro-motive force showed an increase of power throughout the day from 235 to 242; but the resistance of 12 cells 2″ × 2″ at the commencement was $605\frac{1}{4}$, or nearly $2\frac{1}{2}$ as much as in the former case. The latter, however, diminished during the day, owing to the more intimate mixture of the two solutions through porous cells, the battery consequently increasing in energy, and at the end of six hours it stood at 402 turns.

The solution, as recommended by Daniell gave the stronger energy, the resistance of the liquid of 12 cells being about 248, and the available energy the cell equal to about 19 turns.

The condition, then, under which a battery having surfaces of zinc and copper 2″ × 2″

in action at $\frac{1}{4}$ of an in. apart, stands, is this: $F = \frac{E}{20\frac{1}{4} + 19} = \frac{E}{39\frac{1}{4}}$; and as here the value of L is greater than w, it is evident that such a size of plates is disadvantageous for a Daniell's arrangement.

The amount of negative metal in this battery is that comprised in a hollow cylinder of copper $3\frac{1}{2}$ in. diameter, and varying in height according to the power desired. Suspended in the centre is a zinc rod, that employed at Chatham being $\frac{3}{4}$ of an in. in diameter and 20 in. high. If, then, we take for the area of the mean section of the fluid the surface of a cylinder 20" high and $2\frac{1}{8}$" diameter, being the mean of the diameters of the zinc and copper cylinders, we shall have a total area of nearly 134 in., at a distance of $\frac{11}{8}$ of an in.; but it has been found above that a surface of 4" at a distance of about $\frac{1}{4}$ of an in. opposes a resistance of $20\frac{1}{4}$, and hence a surface of 134 in. at a distance of $\frac{11}{8}$ of an in. would oppose a resistance of $2\frac{1}{2}$, leaving an available energy $= 39\frac{1}{4} - 2\frac{1}{2} = 36\frac{3}{4}$ the cell, when porous earthenware is employed as the intervening diaphragm.

Daniell, however, remarks that ox-gullet opposes less resistance than earthenware; and if we assume the resistance to be diminished by this substitution to $1\frac{1}{2}$ turn the cell, it will be giving the battery every advantage; and then the available energy to each cell will be $37\frac{3}{4}$ turns for firing the small platinum wire when placed in the galvanometer; or allowing, as we did before, that one-third greater force is required to fuse it when in contact with powder, the available energy a cell will be reduced to 25 turns.

Supposing, then, that the Daniell's battery, of the arrangement described by its author and the size above specified, is required to be applied to the explosion of a mine, its power the cell, as compared with the small Grove, would be about as 25 to 32, or 3 to 4 nearly. Now, the weight of 10 cylinders of Daniell's battery charged is 137 lbs., whereas 10 cells of Grove's do not weigh 8 lbs.; and further, the Daniell is much more complicated in its arrangement.

McCallan's plan of substituting cast iron for platinum was tried. The electro-motive force seemed to be about the same as in the Grove's; but as it seldom remained constant, owing to the dilution of the nitric acid and destruction of the iron, it was not easy to determine it with accuracy. It oscillated between 408 and 413, that of Grove's being 410. The resistance also of the liquid being at the commencement the same as in the Grove's, it might seem that iron, being cheaper, could be advantageously substituted for platinum; there are, however, some material objections to the substitution. The nitric acid destroys the iron during the whole period that the battery is kept charged, and the more so as the acid gets diluted, forming a solution of nitrate of iron in nitric acid, and thus is every moment deteriorating its own power of absorbing hydrogen, the battery consequently falling in energy. The nitrate of iron also impregnates the porous cells; and in dismantling the battery it is necessary to soak them for some hours in water, to be frequently changed, before permitting them to dry, otherwise the iron salt crystallizing in the cells will crack the earthenware. In addition to this, the action of the nitric acid on the iron is sometimes so great as to cause the acid to boil over, necessitating a rearrangement of cells.

All this trouble and uncertainty is dispensed with by the use of platinum, which is uninfluenced by the acid; and, though the first cost of a platinum battery is much greater, in the end it will be found both cheaper and more efficacious.

The substitution of a saturated solution of nitre and sulphuric acid in equal proportion was tried with the battery of McCallan. This also is a most troublesome arrangement; it is very inconstant, so much so, indeed, as to be quite unsuited for circulating energetic currents; it is continually boiling over, and however well it may answer for experimental researches in a laboratory, it should never be trusted for the explosion of mines. Its electro-motive energy varies according to the amount of force required to circulate; but for the quantity necessary to fuse the platinum wire it never exceeded $\frac{3}{4}$ of Grove's, and only came up to that occasionally. The object of this substitution of nitre for nitric acid is stated by McCallan to be economy; but it has been shown that Grove's battery can be kept charged at a cost of $\frac{1}{16}$ of a penny a cell an hour.

If, however, nitre could have been trusted to excite a battery, even in an inferior degree, its application would have been worthy of further inquiry, as it might sometimes happen in the field that the supply of nitric acid should fail; but so long as gunpowder remained in store there could be no difficulty in obtaining a suitable solution of nitre, by simply boiling up powder and filtering it through blotting paper. The application of this ingredient however, as we have before said, gives very precarious and uncertain results, and should never be resorted to by any but those who have had long practical acquaintance with voltaic phenomena.

We now come to another class of batteries, namely, those in which but one kind of solution is employed, the use and complication of porous cells being thus dispensed with. It was on this principle that the voltaic battery known by the name of Wollaston's battery was constructed. The defects in its mode of action, which have been explained in the first part of this paper, suggested the employment of either cast or wrought iron as a substitute for copper; the rough surface thus presented to the evolving hydrogen favouring its escape. Subsequently Smee substituted platinized silver, that is, silver on which the black powder of platinum had been previously thrown down, thus presenting an infinity of small points to aid the escape of the gas.

Probably for the circulation of currents of inferior energy, such as are suitable for electro-plating, the operation of a Smee may be perfect, and no obstruction occur by the detention of the gas; but when a force necessary for fusing platinum wire is required, the quantity of gas generated is by no means satisfactorily evolved. In fact, the battery, as it were, chokes itself by its own exertions; and if three or four successive demands are made upon it in the course of a few seconds, its power of igniting platinum wire entirely disappears,—nor does it return till the cells have been allowed to rest, and thus set free the hydrogen.

The battery from which these experimental results were obtained was identical in size and construction with the second-sized Grove before described, which was made similar to this for the purpose of ascertaining their comparative merits.

The electro-motive force of Smee's battery, ascertained when it was acting under the most favourable conditions, was, as compared with Grove's, 116 to 410, and the resistance of the liquid stratum of 12 cells = 35; that of a Grove of the same size having been found to be 74½. The available energy of 12 cells of this size = 197 turns. The equation then representing the condition under which this principle of battery circulates a force F would be represented by

$$F = \frac{E}{3 + 16\frac{1}{2}} = \frac{E}{19\frac{1}{2}},$$

that is, each cell has a command over 16½ turns of standard wire when a force sufficient for fusing platinum wire in the galvanometer is required; and as ⅓ greater force $= \frac{E}{13}$ is necessary for producing the same result when in contact with powder, the command would be diminished to about 10 turns a cell; a Grove of the same size commanding about 40 turns a cell; and a Grove ½ the size about 30 turns a cell, which shows clearly at what expense (even supposing Smee's principle capable of being trusted for energetic action) we obtain simplicity of arrangement, and dispense with the use of a second acid. The size and form of the Smee with which the experiments were made are the most convenient if a Smee must be used for the explosion of powder, namely, a surface of metal = 4" × 4" in each cell. And yet three pairs of this are but equal to one of a Grove, whose cells are but ½ the size.

As the Smee is superior in every way to the Wollaston and to the zinc and iron battery mentioned above, it was of no use to examine the respective merits of the two latter forms of voltaic apparatus. One form of battery, however, remains to be examined, namely, that of Dalgleish. Its principle of action has been before noticed. It consists of an arrangement of 12 platinum cups ¾ of an in. diameter and 2" deep, over which are suspended, attached to a bar, 12 cylinders of zinc ½" in diameter. The battery is charged very readily by putting into each cup ⅛ of an ounce of nitric acid. At the moment voltaic action is required, a pressure of the hand on the bar immerses each zinc in its own cup to a depth of 1½ in., and at the same time completes the usual connections, causing an immediate and energetic action. The withdrawal of the hand allows the zinc to be removed from destruction by the elastic bands.

The electro-motive force of this battery as compared with Grove's, using the same nitric acid in each, was as 344 to 410, and the resistance of the liquid stratum of 12 cells = 66 turns, or 5½ turns a cell. The available energy of 12 cells = 622 turns or 51⅚ a cell. The equation then representing the circulation of a force F stood $F = \frac{E}{5\frac{1}{2} + 51\frac{5}{6}} = \frac{E}{57\frac{1}{3}}$, from which it will be seen that while this battery is but little inferior to Grove's in electro-motive energy, it has an advantage over it, in that its liquid stratum opposes much less resistance in proportion to its section, this being due to the absence of Grove's diaphragms.

Also in looking at the value of L as compared with e, it seems as if this battery could be advantageously reduced in size. The mechanical arrangements of the battery, which are somewhat complicated, seem crowded even now into as small a space as they can well be put with safety; and any diminution of cells that could be made would sensibly increase the portability of the battery, as the zinc and platinum comprise but a small part of the actual bulk. The small resistance of liquid in each cell is partly obtained by the extreme contiguity of the zinc cylinders to the inner surface of the platinum cups, the distance being but ⅛ of an in., and partly to the absence of porous cells. The successive wear and tear of the zinc will tend to increase the value of L, and diminish e. The advantages, then, of the Dalgleish principle are the simplicity gained by the use of only one acid, thus dispensing with the necessity for porous cells, and the extreme readiness with which it can be charged for action; it is, however, more complicated than Grove's in its mechanical arrangements, which require skilled labour of a higher degree than could generally be met with in the field to effect repairs. It is also more liable to be damaged by carelessness or accident, as it presents more assailable points.

The power of each battery, taken in conducting wire of 250 grains a yd., which, for reasons presently to be given, we have taken as the best conducting medium for general service, would enable one charge to be fired very readily at a distance of 250 yds., or in a circuit of 500; and if the requirements of a battery were limited to this, we should, where rough handling was not to be expected, prefer Dalgleish's battery to Grove's; but on service we presume far greater circuits will occasionally require to be overcome; if, for instance, a mine has to be exploded at a distance of half a mile, about 38 or 40 cells of each would be required to be placed in series, and then the arrangement of elastic bands and of the development of electric excitement by pressure of the hand becomes somewhat troublesome. The Grove is also more perfect in its chemical action, as the hydrogen set free by the decomposition of the water is immediately absorbed by the nitric acid; and the consequence is that as soon as the circuit is completed we obtain the whole power of the battery. In Dalgleish's arrangement the power visibly increases after the immersion of the zincs, probably owing in part to the heat occasioned by the intense action of the nitric acid on the zinc. This property of the battery is detrimental to firing a number of charges simultaneously in a circuit, and can only be overcome by immersing the zinc cylinders first, and then making connection with the poles. These points will present themselves with greater force to any one operating with the two batteries than they can be expected to do in any description on paper.

The actual cost of constructing the two descriptions of batteries will depend in a great measure on the price of the platinum, which is by far the heaviest item in each. Grove's battery hitherto, to save expense, has been made with platinum foil. Ward, however, prefers employing sheet platinum, of about 120 to 130 oz. to the superficial ft., for the negative. Whether foil or sheet platinum is used makes no apparent difference in the energy of the combination; but as the former is liable to tear, it would in the end be no economy to use it.

The approximate estimate of the cost of 12 cells of each description of Grove's battery, and that of Dalgleish's, is as follows:—

Platinum-foil Battery.—$\frac{3}{4}$ oz. of platinum foil, cells, troughs, zincs, and fittings, 3*l.* 2*s.* 8*d.*

Sheet-platinum Battery.—3·63 oz. platinum, cells, and so on, 7*l.* 2*s.*

Dalgleish's Battery.—9·96 oz. platinum, $\frac{1}{4}$ oz. pure gold, zincs, castings, and fittings, 17*l.* 10*s.*

Comparing the two Grove's, though the second is more than twice the cost of the first, it will prove more economical on service, when it is considered that 5*l.* worth nearly of material out of 7*l.* 2*s.* worth, is, with ordinary care, absolutely indestructible. Dalgleish's battery cannot cost less than 17*l.* 10*s.* for 12 cells, the arrangements requiring also more than ordinary skilled labour to complete. Assuming, then, the Grove's sheet-platinum battery to be on the whole more economical, its cost a cell, as compared with Dalgleish's, is about 1 to $2\frac{1}{2}$. The cubical space which they respectively occupy is as follows:—

12 cells of Grove's (in two box batteries) = 14" × 4" × 4" = 224 inches.
" Dalgleish's .. .. = $11\frac{1}{2}$" × 4" × $7\frac{1}{2}$" = 345 "

Their comparative weights when empty are, Grove's 8 lbs., Dalgleish's $10\frac{1}{2}$ lbs.; the latter, however, would not require two-thirds of the weight of acid to be carried with it on service, and that only of one description; and though these differences may appear insignificant, they will not seem so when the quantity of available energy required in the field comes to be considered.

Assuming, as a basis of comparison, that it would be desirable to have always a power available for firing one charge at the distance of half a mile, through the conducting medium and with the bursting charge which has been selected; and also that the same number of spare cells should be kept at hand to replace those fractured or undergoing repair; the following statements will show the approximate cost, weight, bulk, and other particulars in each case:—

	Grove's.	Dalgleish's.
Cost of construction of batteries ..	51*l.*	110*l.*
Weight of batteries	54 lbs.	70 lbs.
Bulk of "	1400 cub. in.	2300 cub. in.

We call attention to the extreme ingenuity displayed in the arrangements adopted by Dalgleish, to carry out his principle for producing voltaic action, as, for example, in the ready method of withdrawing the zinc cylinders from the attack of a most destructive acid, and in the plan of making the connection of the several cells, which is most original, and cannot be done justice to by any description. He combines metals and acids, so as to produce a high degree of voltaic energy by a mode that may be considered perfect; and though, on the whole, his battery, as submitted, is not so perfect in its voltaic action as Grove's, is more sensible to rough usage, and for these as well as the other reasons stated, not so applicable to operations in the field, yet it so surpasses the batteries of every other principle, as to entitle the inventor to special thanks for the successful application of a principle which it has never before been considered possible to turn to account.

To close the inquiry into the motive power, the following, as far as experiments made with some haste tend to prove, are the comparative electro-motive forces of the several principles Ward examined:—

Grove, 410; Daniell, 235; Smee, 116; McCallan, 410; Dalgleish, 344.

The zinc, iron, and nitric-acid battery is that intended by McCallan's.

Or, if we take E to represent the absolute electro-motive energy of Smee's,

$3\cdot54\ E$ = Grove's; $2\ E$ = Daniell's; $3\cdot54\ E$ = McCallan's; $2\cdot98\ E$ = Dalgleish's.

Now, the mechanical equivalent for producing fusion in Smee's was found to be $\frac{E}{19\frac{1}{4}}$, from which the several expressions for the other batteries may be deduced.

Conducting Wires.—With respect to the conducting wires, two factors are concerned in the power of resistance of any one length to the circulation of the current, namely, the metal of which it is composed, and the area of the section; the resistance varying directly as the specific resistance of the metal, and inversely as the sectional area.

Copper, it has long since been decided, is the metal whose specific resistance, where economy is taken into account, is the least; and it only remained to decide the area of the section, or the diameter of wire to be used.

Now, considering that by increasing the number of plates in series we are able to overcome any amount of resistance, it is as well to reduce the diameter of the conducting medium till the value of the copper wire destroyed (some portion must always be expended in an explosion) is reduced to a comparatively insignificant quantity, that is to say, such as would about balance the destruction of zinc and consumption of acid necessary to overcome the resistance consequent on a still further diminution.

The Gutta-percha Company supplied copper wire covered with gutta-percha, at prices from 9*l.* to 21*l.* a mile, the difference being due *solely* to the greater or less quantity of gutta-percha covering, and not at all to the weight of copper furnished. The thickest of these averaged about 250 grains a yard, the smallest about 160 grains. As the former was, of course, the superior conductor, was equally portable, and of no greater expense than the smaller size, it may be the best size for a conducting medium. It is about $\frac{1}{16}$ of an in. diameter.

This sized wire when covered with gutta-percha is very flexible, and can be easily coiled on a reel; two miles in length would easily pack in a cubic yard: its conducting power roughly stated is such that $1\frac{1}{4}$ yd. of it would be equivalent in resistance to one turn of the rheostat wire, and making this allowance, the measures before stated can be easily reduced to corresponding lengths in this wire.

The degree of covering required to ensure perfect action depends on the nature of the explosion required; if an explosion is to be made under water, when only one wire is required for completing the circuit, the most perfect covering is desirable, and the cost of the wire so covered would be 21*l.* a mile; but for any explosion on land, where a return wire is always necessary, that sold at 9*l.*, 10*l.*, and 11*l.* a mile is sufficiently isolated, especially if the wires leading to the mine are not buried under the ground, or, if buried, kept as far apart as possible. In no case would we recommend lapping the wires, leading to and returning from the mine, side by side, as has hitherto generally been done, for whatever advantage the practice may possess, the chances of failure in consequence are many. If, for instance, in burying it the spade by chance should lay bare the surface of one, it would probably also do the same with the other wire; or, again, if from extraordinary heat the gutta-percha should get soft, which it will do at a temperature of about 160° Fahr., a twist in the rope may bring the two wires together, and the covering afterwards hardening would prevent their separation; and, above all, if a fracture should take place it would be very difficult to find on which wire and whereabouts it had occurred.

Gutta-percha is the best covering for the conducting medium, as it is the only means by which perfect isolation can be obtained under every circumstance.

Bursting Charges.—There are two descriptions of bursting charges before the scientific world, one of which has been long in use, and in which a thin platinum wire, forming part of the circuit, is brought to such a heat as to ignite the surrounding powder; and another, the invention of Mr. Brunton. The company with whom this gentleman was connected had been in the habit of what is familiarly called vulcanizing the gutta-percha which covered the wire, to render it pliable even in the coldest temperature, and this led to the discovery of the fuze in question. By the vulcanizing process, sulphur and carbon become incorporated with the gutta-percha in a manner, so to speak, almost chemically perfect. These two act on the enclosed copper wire, and in process of time produce on its surface a species of sulphide, portions of which, when the wire is withdrawn, remain adhering to the inner surface of the gutta-percha covering. This inner surface, which before was simply gutta-percha, and therefore a non-conductor, has now a feeble power of conduction given to it by means of the minute particles of sulphide of copper and carbon. The conducting power is however very feeble, and seemingly in no two portions the same; but whatever the amount of resistance may be, if it can be overcome sufficiently to circulate such a force as will ignite the sulphur and carbon, the desired effect is obtained.

That the degree of heat, or what is generally termed quantity, required for this need not be anything approaching to that for fusing a platinum wire, may be easily conceived, if we compare platinum, which no amount of heat from a smith's forge will melt, and the elements sulphur and carbon, which are combustible at moderate temperatures; yet that the degree of resistance they offer to the passage of the current must be great, may be judged, when it is stated that 48 cells, and even more sometimes, of Grove's reduced battery are required to inflame them close to the battery. These same 48 cells would explode a mine, by means of the platinum fuze, at a distance of ¾ of a mile very readily.

In order, however, to cause any sensible current to pass through these sulphides, it is necessary to close all other channels of communication, that is, to break the circuit of the copper wires; then, with a sufficiency of power to overcome the resistance, a combustion with powder in contact will produce the desired explosion; and on this principle the bursting charge is made, a part of the copper circuit being broken and the sulphuret surrounding that part being laid bare and covered with powder.

Here, then, we have two modes of igniting powder at a distance, namely, by the fusion of platinum wire, and by the combustion of a compound which seemingly is a sulphuret of carbon and copper; in the former, the medium being metallic, and, therefore, a good conductor, requires at the same time a high degree of heat to fuse it; while in the latter, the sulphide, though opposing a very great resistance to the flow of the current, ignites even when a considerably less quantity is actually passing.

Now, bearing this in mind, and also Ohm's theory or law regulating the circulation of divided currents, namely, that the quantity flowing by each of two or more portions simultaneously is in the inverse ratio of the resistance of each, the following characteristics of these two descriptions of bursting charges, which have been *practically* ascertained, will be easily understood:—

1. To fire a platinum bursting charge, a return wire, where water cannot be made available, is always necessary, for Ward found that the resistance of ¼ of an in. thickness of ordinarily moist earth substituted for it could not be overcome by 48 pairs of Grove's, which would fire the same charge at the distance of ¾ of a mile, or through a circuit of 1½ mile of copper wire of No. 14 gauge; and this shows that the substitution of earth for metallic wire increases the resistance so much as to diminish the quantity circulating to such an extent that the necessary heating effect is not produced.

2. Whatever number of cells—roughly speaking, for of course it cannot be accurately true—it is found necessary to arrange in series to produce ignition in Brunton's fuze at the distance of 1 ft. will produce the same effect through a copper-wire circuit of 1 mile; and an addition of about one-fourth that number will permit of one-half this copper circuit being replaced by ordinarily moist earth.

These two results show that the absolute resistance of this fuze is so great that the addition of a mile of copper wire or a large quantity of earth effects no material diminution in the quantity actually circulating; that is, if E = the electro-motive force, r the resistance of the fuze, and R that of the sum of all the other resistances in the circuit, then $\frac{E}{r}$ is very nearly $= \frac{E}{r + R}$.

3. The same number of cells in series of a battery furnished by the Gutta-percha Works Company, that would ignite Brunton's fuze at the distance of 1 mile, did not produce any visible heat in the platinum wire of the other bursting charges at the distance of 1 ft.; and this will be easily under-

stood from what has been said before, for if, by increasing the resistance of the liquid stratum L we make $F = \frac{E}{L}$ represent a force generated by one plate, which is not capable of heating platinum wire, any number of such cells in series will not heat that wire, as $F = \frac{n E}{n L + w}$ must be less than $\frac{E}{L}$. At the same time if the force required to circulate be less than $F = \frac{E}{L}$ or $= F'$, and L remain constant, the combination of cells in series will have the effect of diminishing w, and ultimately of producing the required force F'.

From this we also learn that the force required to circulate for the ignition of Brunton's fuze is considerably less than that for the platinum bursting charge, and this is still more apparent when we find, as we do, that it does not produce any sensible heat in the platinum wire, much less fuse it.

The battery that gave these results was one that was supplied by the Gutta-percha Company as the best then known for igniting these fuzes. It was a common zinc and copper arrangement, each pair 4" × 4", and each compartment filled up with sand moistened with acid. 100 plates were required to ignite a fuze with certainty, and even 300 would not produce a sensible heat on platinum wire; and this is due to the amount of resistance offered by the intervening stratum, in this case composed of sand and dilute acid: but as sand is no conductor, the only reason for its use is that it enables the batteries to be carried about without spilling the acid. The average resistance of the stratum of sand, supposing it to have been entirely moistened by dilute acid, when a force F was circulating, was found = about 12·8 turns at the distance at which the plates stood, and the available force a cell = 6·7 turns, making the equation representing its action $F = \frac{E}{12 \cdot 8 + 6 \cdot 7} = \frac{E}{19 \cdot 5}$. By the employment of sand, certainly not one-fourth the quantity of liquid can be used, consequently the resistance L must be increased at least fourfold, or = 51·22, which renders it impossible that the force, which we have called F, can circulate in any such arrangement. The use of sand also prevents the evolution of the hydrogen, and so reacts in controlling the electro-motive force. These figures, however, are not given as strictly correct.

4. It is easy, then, to see that the diameter and description of metallic conducting medium for the platinum charge are matters of material consequence, and its standard resistance should in all cases be known; but with Brunton's fuze it is of no consideration to know it, and in this respect Brunton's fuze presents singular advantages.

5. The isolation of the conducting medium to Brunton's fuze must be *absolutely perfect*, whether the explosion is to take place on land or in water; with the platinum-wire charge it need not be so in either. The abrasion of the covering may be so small as hardly to be discovered by the eye, and yet it will be sufficient, if in contact with the earth, to cut off the circuit almost entirely from the bursting charge. From Ohm's law for divided circuits this is easily accounted for. The resistance of the fuze being by far the most considerable one in the whole circuit, any way by which the current can return to the battery, without passing through the charge, will be taken advantage of for that purpose, by just so much the greater portion of the galvanic excitement generated.

When we consider the chances of a covering like gutta-percha—and this is the only covering that is known, which can be employed in practice, and at the same time give perfect isolation—being cut by a flint or by a workman's spade while being buried, and know that however minute the cut no power of battery will be able to overcome the obstacle it forms, or make up for the loss of fluid it occasions, the necessity for adopting some efficacious protection over the gutta-percha, before the mode of firing by Brunton's fuze can be successfully applied in military operations, will be admitted.

That this perfect isolation is not necessary for the platinum-wire fuze is well known, as, even in water, the loss occasioned by a bare wire can be overcome by extra power of battery. The reason is obvious; the resistance in the bursting charge is metallic, and consequently much less than a liquid resistance. The conducting power of iron, which is certainly not superior to that of platinum, is estimated to be to that of water as 400,000,000 to 1, and, therefore, even supposing the proportion of copper surface exposed, on the wire leading to and returning from the platinum bursting charges, to be in this proportion to the area of platinum wire, if their surfaces were brought to within a distance of $\frac{3}{4}$ of an in. of each other, which they never would be in practice, only one-half the quantity of the electric fluid would be cut off from the bursting charge; and if to the distance of 1 ft. apart, not $\frac{1}{16}$ part of the force would be arrested in its passage through the platinum wire. As anything approaching this amount of abrasion can never occur, with ordinary care, in practice, no fear of a failure from a diversion of the currents need be entertained.

The wire leading to the bursting charge having been attached to the two ends of the secondary coil, a few plates of a Greve's battery circulated a sufficient current through the primary wires. The usual contrivance of a temporary magnet, for making a breaking contact, was employed for obtaining intermittent sparks in the fuze.

With this helix, and four plates of Greve's battery 4" × 4", it was easy to explode a bursting charge at the distance of 1300 yds. from the operator, *the return circuit being made through the earth*. It was but necessary to leave one of the wires of the bursting charge in contact with the earth, the other being attached to the wire leading to the voltaic arrangement, with which it was connected. A wire from the other end of the secondary coil led to the earth, which, if touched, was sufficient to explode the charge. There is no doubt that this helix arrangement greatly simplifies the apparatus required for the explosion of these charges, for without it about 120 cells are required to produce with certainty the same explosion. The fact that a return wire for completing the circuit may be dispensed with is a great recommendation for the adoption of this fuze; though at the same time it must be remembered that perfectly dry earth will resist the flow of any current.

In a bucket full of dried sand Ward put two plates of copper, 1 ft. square, at a distance of 1 in. apart, and the whole power be could apply could not overcome the resistance interposed.

With respect to firing a number of charges simultaneously with each of these fuzes, the platinum charge, as may be supposed, has the advantage, for on account of the great resistance added to the circuit, where a second gutta-percha fuze is introduced, the force before circulating is materially diminished, and can only be brought up to the original strength by a great addition of power. The practice Ward had with this fuze was not sufficiently extensive to give him confidence in its application to simultaneous firing; but, to state what has been done, 120 plates of the sand battery before mentioned, or 10 batteries of 12 each, fired one charge well through a circuit of five miles of copper conducting medium, about No. 16 gauge; 96 did the same feebly; 72 could not fire it: 216 plates were required, roughly speaking, to fire two placed in the same circuit; 216 fired three in a circuit of one mile; 360 fired six: and 480 fired eight in the same circuit.

These experiments were made in Brunton's presence, the wires being under water in the canal basin; but it should be remembered that the whole of the circuit was not metallic, a few yards of the return portion being through earth and water, which however, when compared with the great extent of wire, may be considered to have no sensible influence on the result. From them it will be seen that these fuzes are capable of being exploded simultaneously when placed in a circuit; but it requires more practice to determine if they can be so trusted, and it is apparent that each additional one requires a large addition of cells. With the platinum-wire fuze, an addition of two plates for every charge inserted is all that is necessary to establish the circulation of the required force. The platinum charge possesses a great advantage over the gutta-percha fuze, in that its resistance being metallic is uniform, while that of the gutta-percha depends upon the degree of action that has taken place on the copper wire, and especially on the extent of sulphuret circuit; for its resistance is so great that an additional length of one-eighth of an inch causes a great diminution of force in circulation. This last circumstance, combined with the degree of action that has taken place, tend to make the resistance so variable, that sometimes 12 plates have been able to ignite a fuze: it is not safe to apply less than 100 plates of the sand battery. With the platinum charge two plates are always sufficient to overcome the resistance. The gutta-percha fuzes are also liable to deteriorate by exposure to the air, sulphate of copper forming where the sulphides were, and the fuze losing in consequence its inflammable properties. Several modes have been tried of making these fuzes; some requiring six months to mature, and others only half an hour; but the respective sorts seemingly present this property, that the sooner they come to maturity the easier they deteriorate. Both descriptions of fuze have their peculiar advantages. The one may be issued ready made, as an article of store, and the other would sometimes turn to account in an emergency in the field, when the store supply had been exhausted. In fact, the range of inquiry with respect to this description of fuze is very extensive, and well worthy of pursuit. It may be apprehended that such enormous distances will not be necessary in the field: as the cost of the return metallic circuit can be made up by a less expenditure of gutta-percha in procuring isolation: as the resistance of any wire employed can be ascertained with sufficient accuracy and hardly any labour in a few minutes; and, as we shall show, the power required for any proposed explosions, simultaneous or otherwise, can be calculated with far more correctness and confidence than, with respect to the gutta-percha fuze, it is as yet possible to do; and, above all, as the casualties that ordinarily attend the laying out and burying of the conducting medium will have no sensible effect on the platinum fuze, while they have a most important one on the other, it seems right to conclude that, as far as our experience goes, the platinum fuze possesses greater recommendations for use in military engineering.

Having thus decided on the most suitable battery, conducting medium, and bursting charge, it remains yet to point out the rule for calculating the number of cells necessary for exploding any arrangement of charges with them, and at any distances that may be required. The length of the platinum wire of the bursting charge will, of course, influence the resistance of that part of the circuit. From practice, it has been found that a wire $\frac{3}{8}$ of an in. long gives sufficient heat, with the least expenditure of power; and it therefore seems desirable to use that length, as it is as well to adopt some one length, whatever it may be. A length of $\frac{3}{8}$ of an in., weighing 1·65 grain a yard, offers a resistance of nearly 61 turns of standard wire, which is equivalent to about 90 yds. of the selected copper conducting medium, weighing 250 grains a yard; and any extra length employed must be allowed for in the same ratio.

Referring back to the equations representing the working of the reduced Grove's battery, it will be seen that $F = \frac{E}{46}$ is assumed as the mechanical expression representing that each cell of the battery, in fair working order, may be subjected to a controlling resistance equal to 46 turns of standard wire, and yet will fuse the platinum wire in the midst of powder; and that $\frac{E}{68\frac{1}{2}}$ represents the conditions of fusion when no powder surrounds the wire; but as it is the rule for the explosion of powder which we have now to consider, the expression $\frac{E}{46}$ most concerns us, and this expression for the power in strong action, that is, during the first two or three hours, is represented by $\frac{E}{14\frac{1}{2} + 31\frac{1}{2}}$ where $14\frac{1}{2}$ is the average liquid resistance a cell, and $31\frac{1}{2}$ is the energy available for overcoming the metallic resistance.

Roughly speaking, $1\frac{1}{2}$ yd. of the established conducting medium of 250 grains a yard is equivalent in resistance to one turn of the rheostat, therefore the available energy to a cell would be equal to about 46 yds. of the conducting medium; and the resistance of a platinum wire $\frac{3}{8}$ of an in. long, and 1·65 grain a yard, being 60 turns, would be equal to, say, 100 yds. of the wire. For firing a mine at any distance when the battery is in good work, we have then this simple

rule:—Take the whole circuit in yards, including distance up and down shafts, add to it 100 yds. for every charge in the circuit, and divide by 46 for the number of cells. This is the rule that theory points out; it will not be advisable to draw it so fine in practice, but our object at present is to show the principle which regulates the calculation.

Again, when the battery has been six hours in action, $\frac{E}{42}$ and $\frac{E}{63\frac{1}{4}}$ are shown to be the mechanical expressions representing the resistance which each cell has the power of bringing under control whilst circulating a force sufficient to fuse the wire in and out of powder. Taking $\frac{E}{42}$, which concerns us most at this moment, we find by referring back that 23 of the 42 turns are consumed by the liquid resistance of each cell, and only 19 a cell are left to overcome metallic resistance, in fact $\frac{E}{42}$ being $= \frac{E}{23+19}$. These 19, expressed in turns of the established conducting medium, $= 28\frac{1}{3}$ yds. a cell. Having now therefore but $28\frac{1}{3}$ yds. of available energy a cell, instead of 46, the rule for calculating explosion must be modified as follows:—Take the whole circuit as before in yards, add to it 100 yds. for every charge placed in the circuit, and divide by $28\frac{1}{3}$ for the number of cells, and it will be seen that these two rules give widely different results; as, for instance, if a mine were required to be fired at a distance of half a mile, the former would give 41 cells and the latter 66 cells as requisite.

If at any time an economical use of cells is of consequence, it is desirable to have a ready mode of ascertaining what condition the battery is in; for it matters not what that may be, provided we can ascertain it, and apply the proper rule. Fortunately there is a very ready mode of ascertaining with sufficient exactness the power of any arrangement of cells in series at any moment, and of determining the number of cells necessary at any period between the first charging and six hours after. We have, for instance, seen that when the battery is in good action $\frac{E}{68\frac{1}{3}}$ is the force necessary for firing one platinum wire placed in the galvanometer, that double this force or $\frac{E}{34}$ will be required to fuse two side by side; similarly, a force represented by $\frac{E}{23}$ is required for firing three, $\frac{E}{17}$ for four, $\frac{E}{13\frac{2}{3}}$ for five, $\frac{E}{11\frac{1}{3}}$ for six wires, and so on; these results all depending on the figure $68\frac{1}{3}$, which at this period represents the electro-motive energy of the battery in turns of standard wire.

Whatever may be the number of wires that can be fused side by side, the resistance of the liquid stratum cannot be affected by it; and while the electro-motive force a cell remains at $68\frac{1}{3}$, the fact of being able to fuse any number of wires side by side shows that the resistance of the liquid stratum cannot be so much as the denominator of the fraction representing the force required for such fusion. For instance, if five wires can be fused side by side, the resistance of the liquid cannot $= 13\frac{2}{3}$, for if it did, the force $\frac{E}{13\frac{2}{3}}$ would be exactly balanced by the resistance, and could not circulate; if six, it cannot equal $11\frac{1}{3}$. Having thus ascertained that five wires can be fused, and not six, it would be quite safe to call $L = 13\frac{2}{3}$, and as $\frac{E}{46}$ represents the force necessary for fusion in powder, it is perfectly certain that at that moment the available energy a cell for an explosion, in turns of standard wire, cannot be less than $46 - 13\frac{2}{3} = 32\frac{1}{3}$ turns = 48 yds. of selected medium. Similarly, if but four wires can be fused, it will be perfectly safe to allow 44 yds. of selected medium a cell; or if but three, 35 yds. a cell, the resistance of the liquid at this period approaching 23 turns.

At the end of the day of six hours it has been seen that the electro-motive force has fallen in the proportion of $68\frac{1}{3}$ to 63. And the available energy a cell will be reduced as follows: if four wires fuse and not five, to 39 yds.; and further, if three wires fuse and not four, to 32 yds.; and it would not be possible to fuse five wires, with electric energy at 63, at any intervening period, but an allowance of $1\frac{1}{2}$ per cent. an hour for the diminution of the electro-motive force will give the available energy a cell at that time.

This detail has been given to show the principle of the rule and its amount of accuracy, but in practice the whole may be combined into this simple one. Previous to firing a mine, when all the plates are arranged and connected, insert five wires in the slits of the galvanometer, and place the whole series on to fuse it. In all cases it is desirable to put on the *whole* number of cells you intend applying to the explosion required, as by this means you obtain a practical proof of what that combination, with all the errors the manipulator may have committed in arranging the battery, is able to perform; and you must take care *not to touch the connection* of the battery after you are satisfied as to the power it presents for your use. If a fusion takes place, allow 44 yds. of circuit for every cell; and if the number of cells employed do by calculation cover the range, reckoning the charge as 100 yds., you may feel confident in the explosion taking place as soon as the connection is made—if there are not sufficient cells, add one for every 44 yds. over. If only four wires fuse, allow 39 yds. a cell; if only three, 32 yds.

The trial should be made with all the cells that it is proposed to use, and if any are subsequently added it should be repeated; for the more cells there are in combination, the more accurate is the result. The advantage of the trial is that the result immediately points out any mistake that has been made in charging the cells, or in arranging them, and also if that mistake is of any material consequence; and it may be assumed that the same series of this size of plates that will fuse five wires side by side, will as surely command a circuit of 44 yds. for every cell.

It is customary previous to an explosion to test the wire circuit by a galvanometer needle, to ascertain if the circuit is entire; but it seems to me equally necessary to test the power of the battery. The test explained does not require two minutes to apply, and infallibly points out the available force at that moment.

As the diameter of the conducting medium is of great importance, as well as its specific resistance, it is fortunate that the rheostat, by a mode essentially practical, enables us readily to determine the absolute conducting power of any diameter or description of wire. The mode of doing this has been explained before, and need not now be repeated; it will be sufficient to say that the probable error of a single observation with Grove's battery does not exceed $1\frac{1}{2}$ per cent. (for which an allowance can always be made on the safe side), and that any one accustomed to use the instrument could in an hour ascertain the resistance of any platinum wire that may be obtained on the spot, or of two or three miles of conducting medium, as well as every particular concerning the battery, so as to be able to apply them with certainty to explode any arrangement of charges that may be desired.

However, it is essential that every portion of conducting wire issued on service should be proved first. Let there be one description of wire kept at the depôt, which should weigh, for the sake of accuracy, somewhere near 250 grains a yd., and be covered with gutta-percha; but beyond that no precaution is necessary, nor is it essential to know the precise diameter or weight of it. A rheostat *rated*, so to speak, from this standard should be supplied to each branch depôt or head-quarters, and batteries and wires similarly rated should be also furnished in quantities sufficient to meet the probable requirements.

Thus if any portion of the supplies for voltaic purposes should fall short, if the expenditure of all the platinum wire should render it requisite to employ fine iron wire, if it should be necessary to use a different conducting medium in the place of the established one, or a different battery of different acids, or, in fact, if any alteration should be rendered imperative from local circumstances, we shall have a ready mode of calculating the allowance to be made in consequence of the substitutions; and, above all, we shall have the power of comparing practice in different parts of the world, and of estimating accurately the merits of any new combinations, by a report of the experiments of half a day.

The task of perfecting the details of these arrangements must necessarily devolve on those who may be directed to continue this inquiry, as the operator merely touches on the advantages that may be attained through careful attention.

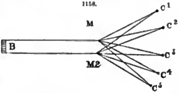
Simultaneous Firing.—It may be necessary to say a few words on the simultaneous firing of a number of charges or mines by one battery, and point how theory guides us to a just conclusion as to the number of plates necessary for any number under any arrangement. Reasoning, then, from the results obtained from Grove's battery, we have found,

1st. That a force represented by $\frac{E}{46}$ is required to circulate, in order to produce an explosion of one bursting charge made with platinum wire $\frac{3}{8}$ of an in. long, and weighing about 1·65 grain per yd.

2nd. It is also admitted that when any force circulates in the manner that a voltaic electric force does, the quantity passing at any one time in all parts of the circuit is the same, but that the heat developed at particular parts depends on the quality of the metal, its diameter, and conductibility. If, then, we place in the circuit any number of short platinum wires, identical in weight and length, and cause a force $\frac{E}{46}$ to circulate through it, we are led to expect that they will all fuse at the same instant, and if they do so, the explosion will also be simultaneous. Now, in order to cause such a force to circulate, it is only necessary that cells should be added capable of overcoming the resistance added by introducing each charge, or cells equivalent to 90 yds. of selected conducting medium; that is, when the battery is strong, two cells a charge, and at other times three cells a charge. This theory, if practically applicable, is productive of great economy both in cells and wire; for supposing twelve charges to be exploded simultaneously at the distance of one-seventh of a mile, or in a circuit of half a mile, by the rule before given, when the battery is in strong condition 44 cells would do the work easily with an expenditure of but half a mile of conducting medium; whereas if each had to be fired by a separate battery, we should require 22 cells and half a mile of wire for *each* charge, making in all six miles of wires and 264 cells.

At the close of the latter day Ward arranged twenty charges in a circuit of 800 yds., and endeavoured to fire them by 48 of Grove's small cells, when only fifteen exploded. Twenty charges, it will be seen by the rule given, were more than the battery of 48 cells could bear; for, allowing one cell for each 46 yds. of circuit (17), and two for every charge (2 × 20), would give 57 cells as necessary; but, as he had not that number, 48 were tried, and failed. In practice it is always best to be on the safe side of the rule, and even to add a dozen cells to the estimated quantity to make sure.

1158.



Such is the imperfect practice which Ward had with the smaller description of platinum wire in the bursting charge. We will presently sketch out the rules for guidance in making future trials; but we first notice the following mode of simultaneous firing, which has been before greatly recommended for its safety.

Supposing B, Fig. 1158, to be the battery, and $C_1\,C_2\,C_3\,C_4\,C_5$, five mines to be fired. At a convenient distance from B two mercury cups $M\,M_2$ should be placed, a wire from each mine leading

to each cup, and a pair of wires from the cups to the battery. This mode of arrangement has the advantage of connecting each mine directly with the battery, and making its explosion independent of any error that may have occurred in any of the other mines. So far it has great advantages, and we also save five pairs of wires, which would have been required to cover the five distances, B C_1, B C_2, &c., and it only remains to determine, by reference to the preceding investigation, what power of battery is necessary to explode the five simultaneously.

As it is evident that the battery B must, when the distances C_1 M, C_2 M_2, &c., are all equal, circulate the same amount of force through each of the bursting charges C_1 C_2 C_3 C_4 C_5, and as each platinum wire must be brought to a state of fusion in surrounding powder, the force to fuse all, or that flowing along B M and M_2 B, must be five times that for fusing one. Now $\frac{E}{46}$ in standard measure is assumed as a representation of the force for fusing one wire in powder, therefore $\frac{E}{\frac{1}{5}46}$, or say $\frac{E}{9}$, will be that required for fusing all. With the reduced Grove arranged in series no number of cells could circulate this force: because, as before stated, the liquid resistance is more than 9, or $= 14\frac{1}{2}$; and it then follows that, unless we can reduce this resistance L, we cannot, with the Grove in question, explode these five charges simultaneously.

There is, however, the following ready mode of reducing the amount of this resistance. Imagine a current of electricity flowing through a circuit of wire B C D, the parts of which B C, C D, and D B, Fig. 1159, being identical in all respects, will oppose an equal resistance for equal portions to the circulation of the current. Now let the portion C D be increased to double the size, or, what is the same thing, along that portion of the circuit let another wire identical with C D be placed, carrying the electric fluid from C to D concurrently with C D, and the effect will be that the resistance of the length C D of the circuit will be reduced to one-half, or, if a third wire be added, it will be reduced to one-third, and so on.

1159.

1160.

Now, altering this disposition of the circuit, let us imagine one battery B, Fig. 1160, say of 12 cells, circulating a current B C D as before, having another, identical in all respects, placed alongside of it, the two zincs being connected, as also the two platinums, and the current circulating in the direction Z P D C. Banishing for a moment from the mind the idea that the electricity is being generated there, which circumstance cannot affect the reasoning, it will be seen that if the resistance of 12 cells before was 12 L, the resistance by this new arrangement *of this part of the circuit* has been reduced to 6 L; or imagining the two batteries B and B, each of 12 cells, to be now one battery, the resistance of the 12 cells of this new machine is now but one-half of what it was in the old one; and if a third battery was put alongside, the resistance of the combination would be 4 L, and so on. We can therefore make a battery, *without any more trouble than that of altering the modes of connection*, which shall give a resistance of liquid of any degree we please; and therefore we can circulate *with economy* any amount of force, or in fact form a battery suitable for *any* purpose.

In the case we have taken, we require to circulate an amount of force expressed by $\frac{E}{9}$ in standard measure, where R = L + w = 9. The most economical mode, theoretically speaking, to circulate this is to make a battery in which L = $4\frac{1}{2}$, leaving $4\frac{1}{2}$ of standard measure for each cell's available energy; but, on practical considerations before noticed, L should be somewhat less than w.

The resistance of each cell of the Grove battery adopted has been shown to be about $14\frac{1}{2}$. Now, five batteries arranged abreast will reduce this to $\frac{14 \cdot 5}{5}$, say 3, leaving 9 − 3 = 6 turns = 9 yds. of adopted conducting medium as the available energy a cell; and if in the case before us we suppose the distance M B to be one quarter of a mile = 440 yds., and the distances M C_1, M C_2, and so on, each = 100 yds., the mode of calculating the number of cells to produce instantaneous explosion of these five thus arranged would be: circuit M C_1 M_2 including platinum fuze = 200 + 90, then the resistance of five concurrently would be $\frac{290}{5} = 58$; to this add 440 × 2 (= 880), giving 938, and dividing by 9 yds., the available energy a cell, will give 104 cells for the number in combination five *deep* in series, or 104 × 5 = 520 cells in all.

Now, by the other mode of simultaneous firing, a much less number of cells will be necessary: any one of these charges could have been fired by an arrangement of 30 cells with ease, and as many more introduced into the circuit at the rate of two or at most three additional cells for each charge.

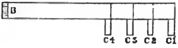
The reason for this immense difference in the number of cells necessary in the two modes is that, in the case where all the platinum wires are placed in one circuit, it is not necessary to increase the *amount* of circulating force, because the quantity flowing through one charge helps to raise the heat of all; but in the latter arrangement it is necessary to supply heat sufficient to melt five platinum wires, of one thickness, simultaneously; and as they *share* the electric

current established *between them*, five times the amount of force is necessary. If, then, an equation $\frac{E}{L + w} = F$ represents a battery in which $L + w$ are economically arranged to produce a force F, then $\frac{E}{\frac{L}{5} + \frac{w}{5}} = 5\,F$ represents a disposition for fusing five such wires. Now $\frac{L}{5}$ it has been shown can only be produced by placing five cells abreast, and as $\frac{w}{5}$, representing the available energy of a cell, is only *one-fifth* of what it was before, it requires that five times as many should be arranged in series, end on, to overcome any given resistance.

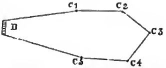
These are the only two principles of firing simultaneously that are practised, for the following arrangement is but a modification of the second mode, as will be apparent, and the same mode of calculation applies to it. We have, by the second arrangement, a mode of exploding any number of charges simultaneously, and from the arrangement itself it is evident that a failure cannot take place, for each charge will be quite independent of the others. At the same time it is very doubtful if any economy is secured by this arrangement. Supposing B M C_1, in Fig. 1158, to be 540 yds. as before, $\frac{540}{23} + 2$ gives 26 cells as quite sufficient for exploding that one mine, and therefore $26 \times 5 = 130$ cells would be enough to explode all five simultaneously, if *each charge* had a pair of wires leading to B. Now, to economize *four* pairs of wires along M B, or to save the trouble of laying out two miles of wire, we are obliged to employ $520 - 150 = 370$ extra cells; and it becomes a matter for consideration whether the extra expenditure of trouble and acid, at the source of supply, does not more than counterbalance the labour of arranging the wires. In fact, the first principle of simultaneous firing, namely, that of placing all charges in one circuit, is the *only* economical mode, and that it requires but a knowledge of the principles which we have endeavoured to make clear, without any finessing in practical details, to ensure success with it on every occasion. The great cause of failures in simultaneous explosion has been the want of sufficient power; and if any one will take the trouble to examine, on the principle of Ohm's theory, the statistics of recorded failures, they will see that they all thus occurred from a manifest want of power; so that instead of disappointment at their want of success, they will wonder how they ever succeeded.

It has generally been the habit, as a matter of precaution, to solder two wires side by side in a bursting charge, in case one should break; would any one unacquainted with Ohm's theory imagine that if a battery, economically constructed for fusing one wire, were used to fuse two side by side, it would not be able to produce even visible heat in either of the two, or, in fact, that it would require four times as many cells (arranged as explained before) to fuse these two wires? yet sometimes three or four have been so placed. Occasionally two charges are placed thus, C_1 C_2, Fig. 1161, in one powder-box, each (C_1 and C_2) having two platinum wires. If a battery were economically constructed to fuse one such wire, it would require nearly sixteen times as many cells to fuse the four.

1161.



1162.



Suppose, again, Fig. 1162, that a number of charges are arranged in a circuit thus, each with two precautionary wires, and that while the battery is powerful enough to fuse the double wires all round, one of the two wires in one charge (C_1) is broken by some mishap: it is then rendered *positively certain* that, however strong the battery power may be, this (C_1) will be the only charge which will explode, for the *one* wire left in it will fuse before the other pairs will arrive at any visible heat. Ohm's theory explains the cause, and points to this as the certain result.

Again, the conducting wire hitherto used for explosion has been generally $\frac{1}{8}$ of an in. thick, and the platinum wire in the bursting charge sometimes $1\frac{1}{2}$ in. long; now, can it be supposed that it was generally known that the introduction of one such bursting charge in the above circuit was equivalent to adding 1200 yds. of the thick conducting medium, or that an equivalent to this resistance in cells was ever added to compensate for the diminution of force?

These, and many other extraordinary results depending on the principles regulating the circulation of a voltaic current, have given this agent the character of extreme mutability and uncertainty, which it does not deserve, as they were the consequence of an imperfect knowledge of those principles.

From what, then, has been shewn above, as the result of the use of a second platinum wire in the bursting charge, it will be apparent that Ward condemns its application; since in firing charges simultaneously in a circuit it is worse than useless, and is indeed ruinous in its effect. The precaution being resorted to, implies a belief that in case of a single fracture in any one charge, a second wire is at hand to complete the circuit and ensure an explosion of all; but the reverse is the case, as has been shown; and the second wire, the first being fractured, ensures that this charge is the only one which will explode: and yet the usual testing of the circuit by a galvanometer needle, previous to connecting with the battery, will delude one with the hope that all is right; whereas, if only one wire had been used in each charge, the fracture would have been

made apparent at once by the breaking of the circuit, and thus a warning given to repair. In no case should we attempt to place more than one platinum wire in a bursting charge, and that charge should be *only* connected with a pair of conducting wires leading to the surface or end of the tamping: place a second charge, if it is thought desirable; and before finally connecting *either* of them with the wires intended to lead to the battery, test each by the galvanometer to see if the circuit to that point is complete, and then connect only one of them to the main wires leading to the place from which the mine is to be fired.

It will be seen that for whatever purpose voltaic agency may be required, and whatever principle we adopt to circulate the amount of current required, there is a certain size of plates which will do it to the best advantage, depending on the mechanical equivalent representing the value of that force. In the present case the force required was found to be best produced by a Grove's arrangement of the size submitted. When a Smee was tried, though from its simplicity it was preferable to a Grove, it was found that it choked itself, as it were, in its endeavours to circulate the amount required, and consequently its circulation was not constant and not suitable for our purpose; at the same time its electro-motive energy being low, more bulk was necessary for producing any effect. Daniell's battery certainly circulated a constant force of the degree required; but it was inferior in electro-motive energy to Grove's, and, being at the same time more complicated, was rejected, and so with the others.

We have shown that the simultaneous explosion of any number of charges of powder can be obtained, if we can at the required moment establish the flow of such a constant current of electricity as shall produce a fusion heat in every platinum wire placed in the circuit.

It is advantageous, however, that this circulation should be produced with the utmost economy, consistent with certainty; and we have shown that the economical consideration is theoretically satisfied when (E representing the electro-motive energy of the combination, L the resistance of the liquid, w that of the wire, n the number of plates, and F the required amount of current) in the equation $F = \frac{n\,E}{n\,L + w}$, $n\,L = w$, or $L = \frac{w}{n}$; but that practically, for reasons given, L should be somewhat less than $\frac{w}{n}$, the expression $\frac{w}{n}$ representing the available energy to each cell of the voltaic combination.

Now, the battery submitted has been constructed to satisfy these conditions, with the platinum wire which Ward recommends. But it will be evident that any alteration in the amount of current required to circulate would require a corresponding modification of the battery. For instance, if a platinum wire double the thickness of that recommended were substituted, more heat would be required to fuse it, and therefore a greater current must be caused to circulate. This can only be brought about in the equation $F = \frac{n\,E}{n\,L + w}$, where E and L are constant, as they are in any *determined* form and principle of battery, by a diminution of w; and if this diminution reduces w in value below n L, the amount of current required is no longer economically circulated. Nor can it be so till the value of L is also reduced, the principal mode of effecting which is by enlarging the size of the plates. The *diameter* of the platinum wire is therefore an *essential* consideration in determining the size of the plates in any voltaic arrangement to produce its fusion, as very small differences in the diameter of the platinum wire will lead to gross errors in calculating the number of cells necessary for an explosion, and uniform success can never be obtained in the field if the platinum wire has not been carefully selected, and tested as hereafter suggested before its issue from store.

The *length* of the platinum wire employed in the bursting charge is not a matter of the same importance, as a battery of the same sized plates can economically circulate the force required through any length of platinum wire. For it must be borne in mind that by adding lengths of wire we do not call on the battery to circulate a *greater amount of force*, but merely to overcome a *greater resistance* to the circulation of the *same* amount, which can readily be done by increasing the number of plates in series. For if in the equation $F = \frac{n\,E}{n\,L + w}$ we increase w to $w + a$, and so diminish the value of F, we can immediately restore the equation to its former value by adding cells $= \frac{n\,a}{w}$, and the force F will circulate as economically through a resistance $w + a$ by the combination expressed by $\frac{\left(n + \frac{n\,a}{w}\right) E}{\left(n + \frac{n\,a}{w}\right) L + w + a}$ as it did in the first case through w by the combination of n cells.

It is thus quite open to any future operator with the battery submitted, to introduce any lengths of platinum wire into his bursting charge, merely remembering to employ the thickness recommended, namely, 1·65 grain a yard; though $\frac{3}{4}$ of an in. is sufficiently long for all purposes, and possesses the advantage of less liability to fracture than greater lengths.

With respect to the copper conducting medium, that weighing 250 grains a yard, covered with gutta-percha, is recommended; but it is not *essential* that any particular metal should be employed, or that the wire should be of any particular weight, as we have described a ready mode of ascertaining the resistance, in standard measure, of any material of any length.

Mining Operations for Blowing Down the Cliff near Seaford, on the Coast of Sussex, 1850: by Major-General John F. Burgoyne.—Along the coast of Sussex the banks of shingle afford protection to the rich low lands within them from the encroachments of the sea.

The shingle, however, is in a gradual but irregular state of movement from west to east, and

at times a great impression is made on particular parts, that would lead to much damage, if not arrested by projections of timber and planking, between high and low water marks, termed groins. These groins are very expensive, and their useful effects extend but for a short distance.

William Catt, whose family have considerable possessions in the plain between Newhaven and Seaford, a distance of about three miles, considered that by constructing a very substantial groin on a large scale under the cliff near Seaford, which is at the east extremity of the plain above mentioned, and the foot of which cliff was washed by the sea at high water, and thus stopping the progress of the shingle, it would have some influence in protecting the whole extent of the beach to Newhaven.

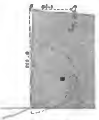
He also considered that the most efficient, lasting, and economical mode of establishing such a projecting obstruction would be by throwing down the cliff, which was nearly perpendicular, and about 200 ft. high, on to the beach, by a great explosion of gunpowder.

In the main feature of the application of the two great charges, there was no difference in principle between them and the three, though there were some in the proposed modes for carrying it out, as will be subsequently explained.

The plan finally adopted was to lodge two large charges, each of 12,000 lbs. of powder, 120 ft. asunder, with lines of least resistance of 70 ft. to the face, and 58 ft. above the level of the foot of the cliff.

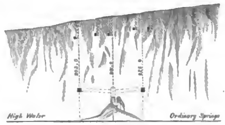
Five smaller charges, of 600 lbs. each, were to be placed in rear, Figs. 1163 to 1168, at a higher

1163.



Section on E F.

1166.

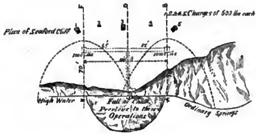


Elevation.

1164.

Section on C D.

1167.



1165.

Section on A B.

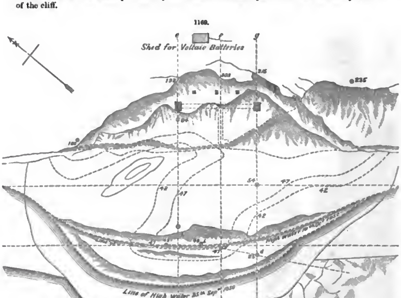
1168.

level, to clear that part from overhanging remains; and the whole to be fired by voltaic batteries, the two main charges first and simultaneously, and the five smaller ones immediately after. In consequence of not receiving in time a supplementary demand of gunpowder, only three of the smaller charges were loaded.

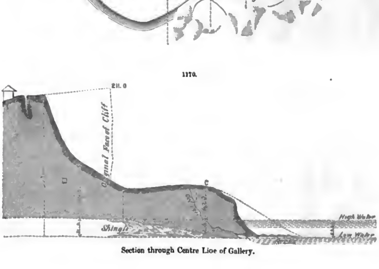
The circuit of the wires connected to the two great charges was completed at the batteries, and on the instant the ignition of both took place, throwing down the face of the cliff for a length of 500 ft., and to the rear 15 or 20 ft. beyond the five shafts, so as to bring down and bury the three upper charges unfired, cracks and fissures extending nearly to the shed in which the batteries were placed.

Figs. 1169 to 1174 show the result of the explosion of these two mines; and on the sections is also described the effect produced by the action of the sea upon the mound formed by the fall of the cliff.

1169.

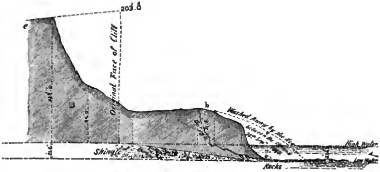


1170.



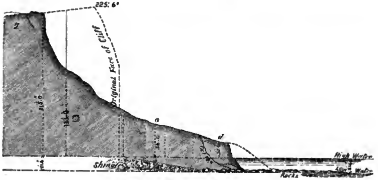
Section through Centre Line of Gallery.

1171.



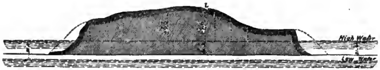
Section along West Line of least Resistance.

1172.



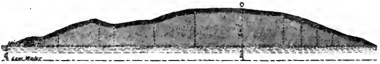
Section through East Line of least Resistance.

1173



Section through L at right angles to Lines of least Resistance.

1174.

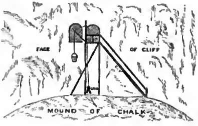


Section through O at right angles to Lines of least Resistance.

The projection of the mound, as first thrown out, was about 300 ft.
The mass thrown down, according to dimensions taken the day after the explosion, was about 200,000 cub. yds., or 292,000 tons nearly, at 121 lbs. the cub. ft., which was found by actual trial to be the specific gravity of the chalk.

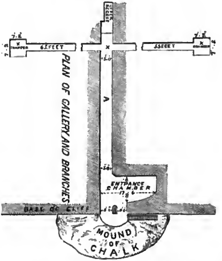
Mining Operations at Seaford.—The opening made in the face of the cliff for the commencement of the central gallery, by which both the chambers were reached, was 35 ft. above the high-water mark (ordinary spring tides), which at this spot was the level of the beach at the base of the cliff. It was commenced from a rough stage supported by scaffold poles, and reached by a common ladder, the stage being necessary in consequence of the impossibility of making any impression on the face of the cliff by men working on the ladder itself. The cliff is composed of a very compact chalk, 121 lbs. to the cub. ft., dipping to the north at an inclination of about 15°, and intersected by veins of flint at intervals of about 15 or 20 ft. Its height was at the site of the western mine 203 ft., and at the other 225½ ft., above high-water mark. The section at the first of these spots was nearly vertical; for the whole height at the second it was only so for about 140 or 150 ft. A mound of chalk, that had fallen a few days before just at the spot, afforded, when levelled on the top, a base 14 or 15 ft. above the beach, on which to erect the scaffolding. As soon as the men had penetrated a sufficient distance into the cliff to be able to work in security, the scaffolding was strengthened, and a convenient platform with a step-ladder constructed for use during the remainder of the operations, Fig. 1166. To this scaffolding was also fixed a crane-post and derrick capable of lifting nearly half a ton, by means of which the sand-bags and chalk used for tamping were raised to the mouth of the gallery by a crab on the top of the mound. See Figs. 1175 to 1177.

1175.

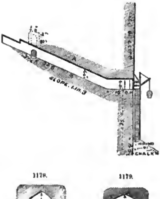


At the entrance, a cave of the dimensions shown by Fig. 1176 was formed, for the purpose of keeping all tools and materials out of the way of the men working at the gallery, and this space subsequently proved of the greatest service, as a depôt for the powder, sand-bags, and chalk, before they could be

1176.



1177.



1178.

1179.

passed along the gallery and branches. Similar advantage was found from a recess, Fig. 1176, at the end of the central gallery, formed by its prolongation, originally as the mode of arriving at the spot where a third service of 2000 lbs. was proposed, which was afterwards considered unnecessary, and the further advancement of the gallery stopped. The use made of these two depôts fully compensated for the cost of their excavation, though, had the rock been of a hard nature, smaller spaces, particularly with reference to the upper recess, would have answered the purpose, and would have been advisable on the score of economy.

The men employed driving the gallery and branches worked in reliefs for the whole 24 hours. For the gallery, three reliefs of four men each were told off; and subsequently for the branches three reliefs of six men for the two, which were carried on for the most part simultaneously. The hours for relieving were 6 A.M., *noon*, 6 P.M., and *midnight*, excepting at periods when the high spring tides prevented the relief passing a projecting part of the cliff at the proper hours, when arrangements were made to equalize the extra time the men were consequently employed. The

work was hardly ever interrupted between 6 A.M. on the Monday and 6 P.M. on Saturday. By compelling each relief to be in barracks six hours before their turn came for work, the men were always fresh at the commencement of their time; and as the working pay was good, and the best miners were thus employed, the average amount of work performed by night fully equalled that by day.

The dimensions of the entrance gallery are given in Figs. 1176, 1177. The content was 47½ cub. yds.; the rate of progress about 16 cub. yds. in the 24 hours.

The main gallery of the section given in Fig. 1178 had an area of 27 superficial ft., so that each lineal foot gave 1 cub. yd. of excavation. The average rate of progress was 8 lineal ft., equal to 8 cub. yds., in the 24 hours.

The branches, of the dimensions given in Fig. 1179, had a section of about 12½ superficial ft.; the rate of progress of the two was at first about 16 ft. = 7·4 cub. yds. in the 24 hours, six men, as before stated, being employed in each relief, instead of four, as in the gallery; but as the distance from the entrance increased, this rate was not maintained, the latter portions averaging little more than 13 ft. in the 24 hours.

		Cubic yards.	Number of Hands employed.	Cost per cubic yard.	Average number of Men in the three Reliefs.
Entrance chamber	47½	164	440	2*s.* 4*d.*	12 to 18
Main gallery	61½				
Branches	55				

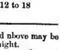
From the foregoing data, the general rate of progress of the works mentioned above may be assumed at 9 cub. yds. in the 24 hours, by five men constantly employed day and night.

In comparing the progress of the gallery and branches, it appears that the former advanced at the rate of 8 ft. in the 24 hours, and each of the latter, though less than *one-half* the area, at an average rate of only about 7½ ft. in the same time. The increased distance of the branches from the entrance would partly account for this difference; but it is, in a great measure, to be attributed to the slow progress made by miners when working to a disadvantage in a very confined space. Had these branches been 5 ft. 6 in. high and 3 ft. 6 in. or 4 ft. broad, it is probable that they would have been completed in rather less time than was occupied by the smaller size adopted, particularly as no gunpowder was used; the subsequent tamping would, however, have been proportionally increased.

The chambers for the two lower mines were cubical, the side of the cube being 7 ft. 2 in., and giving a content for the two of 27 cub. yds., Fig. 1167. The time occupied in their excavation, and in squaring their floors and sides to receive the joists and uprights to support the rough planking with which they were lined, was about 138 hours, making the rate of progress only 4 cub. yds. in the 24 hours.

The five shafts sunk for the five mines of 600 lbs. each, intended to have been fired simultaneously, *directly* after the ignition of the lower mines, were each 40 ft. deep, and of the section shown in Fig. 1180 having an ascent of about 19 superficial ft. The total content of the five was about 140 cub. yds.

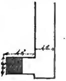
1180.



Three men were generally employed upon each shaft. The stuff brought up was piled round the mouth of the shaft, ready for tamping, and no gunpowder was used, the chalk being of a much softer character than in the gallery, and not intersected in the same manner with flint. The task set to each gang of three men for the greater part of the work was 2 ft. 6 in. for every 6 hours. The average rate of progress for the first three shafts was 3 ft. 7 in., equal to nearly 2¼ cub. yds. a day. The two last shafts, which were only decided upon within a few days of the explosion, were carried on during the night by reliefs. Their progress in the 24 hours was nearly 6 ft. = about 4¼ cub. yds. each shaft.

The returns at the bottom of the shafts, and the chambers for the powder, were as shewn in Fig. 1181. The difficulty of working in so confined a space, and the trouble of squaring the returns accurately so as to admit the boxes containing the powder, were the causes of great increase in the expense.

1181.



The *directions* of the gallery and branches were laid out by a theodelite, with reference to a line assumed as parallel to that joining the centres of the two charges, fixed during the previous survey of the ground, and the inclination of their floors was tested by a mason's level, the miners being provided with a rough level adjusted to the required slope, to direct them during the progress of the work.

The tools used in the main gallery were the common miner's pick, and a large shovel, for which, in the branches, a mining shovel, 2 ft. 3 in. long over all, was substituted. Wheelbarrows were found more manageable in the gallery than miners' trucks, which, owing to the very great inclination at which the floor was driven (1 in 3), were very difficult to hold back when descending the slope filled with chalk, and to draw them up empty. In the branches, which had a rise of 1 in 9 to 1 in 10, trucks were always used; the recess at the end of the gallery, already alluded to, being found very useful for turning them and for keeping tools out of their road.

Ventilation.—The air was so pure in the whole of the galleries, and even in the chambers, that, excepting when the miners were actually at work and the candles burning, no artificial ventilation was required; had any quantity of carbonic acid gas been present, it would, owing to the steep

inclination of the main gallery, have flowed outwards along the floor towards the entrance, and its place have been supplied by a stream of fresh air along the roof of the gallery. In the branches this effect would have been much lessened, from their more gradual rise; and in the chambers, which were sunk below the level of the floor of the contiguous branches, the heavy gas would have settled immediately; but in this instance the air on the floor of the chambers appeared as pure and light as at the entrance. The air-pump by which the ventilation was effected had been used for exhausting the foul air at the bottom of a deep well sunk in the neighbourhood of Brighton; and, by mounting it upon a rough stand, it was made available in the gallery and branches. The tube, secured to the wall about 3 ft. above the floor, was, for the whole length of the gallery, part of the old wooden pipe that belonged to the air-pump; but in the branches, gutta-percha tubes, of 2¼ in. diameter and $\frac{1}{16}$ of an in. thick, were made use of.

By adding length after length to these, as required, the hot impure air breathed by the miners at work was drawn off by the air-pump, which, in fact, was all the ventilation needed. Had the air become foul as the miners advanced into the cliff, this air-pump would not have been sufficiently powerful for the purpose; to be prepared for which contingency, arrangements were made for the use of a blowing apparatus from a foundry at Brighton, which, however, was never required.

The gutta-percha tubes weighed about 3¼ oz. a foot run.

Lighting the Galleries and Chambers.—During the progress of the gallery and branches, the miners worked by the light of candles, in the accustomed manner; but to avoid any risk of accident from the use of lamps during the operation of loading the mines, fixing the bursting charges, and laying and securing the copper wires leading from them, a contrivance was resorted to for lighting the chambers by reflection from plates of bright tin tacked upon deal frames, which plan was previously tried and found to answer perfectly during their excavation. This method originated in a suggestion of Colonel Lewis, founded upon a mode he had practised of obtaining light in a magazine, by reflection from the painted copper door of the building. A board of about 4 ft. square was first covered with bright sheets of tin, and fixed at an angle of 45° with the direction of the centre line of the main gallery, at the spot where the branches turned off nearly at right angles. The light thus first obtained by reflection from the white chalk was very feeble, and hardly perceptible near the extremity of the branches, excepting at one short interval in the day when the sun was nearly in the line of the gallery, and its scattered rays were reflected from the sea (particularly when calm) up the slope; and the smaller reflector was then placed just outside the mouth of the gallery, in such a position as to catch obliquely the first rays of the sun that the overhanging cliff allowed to visit the spot, which was between 10 and 11 A.M., from which hour till sunset, by occasionally moving the outer reflector and adjusting it like a heliostat, to throw the direct rays it had attracted upon the set of plates at the upper end of the main gallery, a brilliant light was reflected along the branches and into the chambers, where the smallest and most indistinct writing was as legible as it would have been in broad daylight. Had the operations extended over a longer space of time, this outer reflector would have been fixed in a frame, and means contrived to render the adjustments in any way required more easy; but, for the short period it was needed, a rough plank to support it, and two or three sand-bags to retain it in the required position, were found sufficient.

Loading the Mines.—The gunpowder (24,000 lbs.) used for the lower mines was supplied at the lowest rate at which the Battle Mills had offered to furnish merchants' blasting powder, of good quality, but inferior in strength to cannon powder in about the ratio of 9 to 13.

It had been made up in flannel bags containing 10 lbs. of powder, nine of which bags were packed in each of the barrels, which were lined with zinc cylindrical cases, having lids fitted to openings on the top, rendered impervious to moisture by a thick coating of waterproof composition. These were sent round to Seaford Bay in a sloop, and landed, almost immediately after the arrival of the vessel (soon after low water), on the beach, before one of the martello towers which had been prepared to receive them until required for use. The whole number of barrels, weighing nearly 130 lbs. each, were carried by hand up the beach, and stored in the tower. The powder required for the mines at the bottom of the shafts sunk above the cliff, which did not form part of the original project, was not applied for at the time that the first quantity was dispatched, and, owing to some delay, did not arrive at Seaford until within two days of the time fixed for the explosion, so that it was only possible to load three of the five mines of 600 lbs. each that had been prepared.

The distance from the tower to the entrance of the gallery, nearly three-fourths of a mile, rendered it necessary to employ three carts to assist in moving the powder along the beach, on account of the time that would have been consumed in conveying all the barrels to the spot upon hand-barrows. A portion of the men were, however, so employed with nine barrows, and a party of thirty sappers, under an officer, were told off for this work, and for carrying the powder barrels up the ramp leading to the foot of the ladder, and passing the bags up the steps into the entrance chamber.

As rapidly as the barrels were brought to the top of the mound at the foot of the ladder, they were opened, and the bags passed by hand up the steps by men stationed at proper distances upon them, the convenient size of the bags enabling this to be performed with great ease and rapidity; and by the time the men went to dinner, one-third of the powder had been piled up in the outer recess, upon tarpaulins previously laid to receive the bags. After dinner, part of the men (twelve) were employed passing the bags up the gallery to the inner recess, also by hand, the men being stationed between 5 and 6 ft. apart, along one of the walls, and the gallery lighted in the manner already described.

Later in the afternoon, the men who had been occupied with the powder barrels were made to line one of the branches, sitting down with their backs to the side of the branch, and passing the bags from hand to hand to the chamber, where they were built up in a compact form, under the eye of one of the officers; the chamber having been previously floored, and lined to the height

of 5 ft. with rough planks, fastened to uprights by copper nails, to prevent the powder from coming in immediate contact with the chalk.

When one-half of one chamber was completed, the men were transferred to the other branch, and both chambers were loaded with half their quantity of powder, the whole time occupied by the above operations being only $6\frac{1}{2}$ hours. Two sentries were then mounted at the entrance of the gallery, and on the following morning the work was recommenced, and the loading entirely completed by half-past 4 P.M. Before leaving work the remaining sand-bags were all filled, and about ninety of these hoisted into the mouth of the gallery by means of the derrick, and taken up to the upper recess, to be in readiness for commencing the tamping as soon as the bursting charges should have been fixed, and the first portion of the wires leading from them secured from any risk of being moved or injured, which was effected by passing them through tubes drilled in strong pieces of scantling, secured across the entrance to the chambers, and fastening them by wooden plugs, and afterwards leading them along the floor of the branches in grooves cut in narrow strips of plank, covered by other pieces nailed over them with copper nails.

The whole of the operations detailed above, from commencing to move the powder from the tower to the completion of the loading of both the mines, occupied 3 carts and 30 men for 11 hours, and 12 men afterwards for about 4 hours.

The lines of least resistance of each mine being exactly 70 ft. and the charge 12,000 lbs., the proportion the latter bore to the cube of that line was about $\frac{1}{28}$, rather more than was originally proposed ($\frac{1}{32}$). $(70)^3 = 343000$ and $\frac{343000}{28} = 12250$ lbs.

Tamping.—The materials used for tamping in the galleries were sand-bags (filled, some with dry chalk, but the greater part with sea-sand) and lumps of chalk. The sand-bags, only 600 of which were supplied, extended about 30 ft. from each chamber along the branches, the remaining length of which, as well as that portion of the main gallery which it was considered advisable to fill up, being completed with chalk hoisted from below by means of the derrick, in large baskets containing 6 bushels, weighing about 9 cwt. The greater part of the sand-bags were lifted into the gallery in the same manner by slings, five or six together.

In the shafts above, the tamping consisted merely in shovelling down the stuff that had previously been drawn up and piled round the opening, the charges not being sufficient to create apprehension of their producing any effect upwards, the line of least resistance in that direction being 40 ft.

The sand-bags filled with dry chalk, free from any particles of flint, were used in the branches for blocking up each of the chambers, and extended about 8 or 10 ft. from them, so as to prevent the possibility of any damp reaching the powder from those filled with wet sand, which were afterwards built in promiscuously with the others.

Large blocks were built across at intervals, and the finer stuff thrown in behind and rammed sufficiently to make a tolerably compact mass, the wires from the bursting charges being secured from injury during the operation by the manner in which they were enclosed in the grooves already alluded to.

The extent of the tamping is shown in Figs. 1176, 1177, and occupied from 18 to 20 men for three days, as also 12 men for one night. The distance from the crossing of the branches down the gallery to the spot where the tamping was discontinued, was only 20 ft. 6 in., which, though not what would be generally considered necessary with moderate charges, the point A being considerably less than the length of the line of least resistance from the centre of one of the mines, was thought sufficient; the section of the gallery being quite insignificant, when the enormous expansion that would be caused by the explosion of the two charges was taken into account. The result proved that this idea was correct; indeed, it is probable that the effect would have been the same if the main gallery had been left entirely open.

In the branches the rate of progress with sand-bags was about 12 ft. the hour, rather more than 100 sand-bags being required for every 10 ft.; they were passed along nearly in the same manner as the powder, the men being necessarily placed at less distances apart, and the branches lit as before, by the tin reflectors.

With loose chalk, the rate in the branches was 7 to 8 ft. an hour, equal to about $3\frac{1}{4}$ cub. yds., the section being $12\frac{1}{2}$ superficial ft.

In the main gallery the rate of progress for the distance tamped, 30 ft. 6 in., equal to $30\frac{1}{2}$ cub. yds., was about 4 ft. 8 in., equal to 4·7 cub. yds. an hour.

The above statement of the number of men employed and the rates of progress, includes those working at the derrick and passing the sand-bags and chalk up to the party at work.

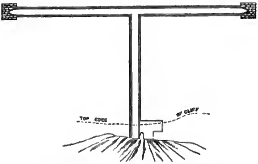
In passing the sand-bags and chalk to the end of the branches from the entrance chamber, from 20 to 24 men where required; from the upper recess, which was also used as a depôt for these materials, 12 men were found sufficient for passing on the sand-bags, and tamping.

At the derrick seven men were employed—two at the crab, three collecting chalk and filling below, and two emptying the basket above, which was in this manner loaded with six bushels of chalk, lifted a height of 22 ft., and returned in $4\frac{1}{2}$ minutes. The same quantity carried up the ladder upon men's shoulders in half-bushel baskets occupied about six minutes with the same number of hands. Another advantage in favour of the derrick was, that there was no difficulty in continuing the work for the whole day; whereas the men could not have stood the fatigue of carrying the baskets up the steps for any length of time.

Description of the Voltaic Battery.—The position of the mines above and below is shown in Figs. 1182 to 1185. The position of the battery house, that is, the shed where the voltaic batteries were placed, and to which the conducting wires from the mines led, is also drawn in Fig. 1185.

The conducting wires from the large mines were brought up the face of the cliff, and then into the battery house.

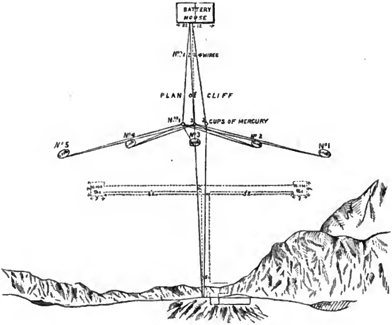
1182.



Plan of large Mines below and Galleries leading to them.

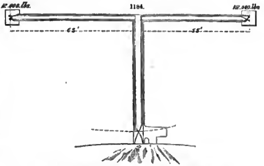
The wires on coming from the entrance of the gallery are passed up the face of the cliff, and are represented in Fig. 1167 by Nos. 2 and 4 wires.

1183.



Nos. 2 and 4 wires lead to the charges below. Nos. 1 and 3 are connected with the five mines above through the interposition of the mercury cups. On the word to *make ready*, Nos. 1 and 2 are attached to one pole of the battery, Nos. 3 and 4 being held one in each hand. On the word *fire lower mines*, No. 4 is connected to the other pole of the battery, and the lower mines explode. On the word *fire upper mines*, No. 3 is connected to same pole as No. 4, and the five upper ones explode. If instantaneous explosion of all mines be required, Nos. 3 and 4 should be previously tied together, and on touching the other pole of the battery all the mines would explode simultaneously.

1184.



Plan of large Mines and the Galleries leading to them.

It was originally intended to have fired the large mines below simultaneously by one battery, arranging the conducting wires as shown in Fig. 1183, that is, the wire proceeding from the battery was to have been carried directly to, and connected with, the bursting charge of one of the lower mines; from this, again, a conducting wire proceeded to the bursting charge of the other, which again was connected by the same means with the other pole of the battery. The whole circuit by this arrangement would have been about 360 yds. Subsequent experiments have proved that it would have been successful. When the time fixed for the explosion drew near, doubts were expressed in influential quarters of the safety of the plan, and as, from want of time, there was no means of proving its practicability by a sufficient number of experiments to remove all doubts, it was thought advisable to adopt the old method of firing each lower mine by a separate battery and a separate set of wires.

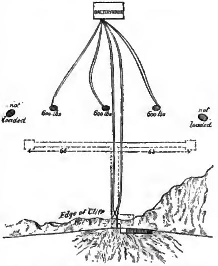
It was originally intended to have fired the five mines above by the arrangement shown in Figs. 1182, 1183. Two mercury cups situated in a convenient position, such as shown in Fig. 1183, had each to receive one wire from each mine; two main wires proceeded from these cups to the battery house, one from each cup.

The object of the cups in this case was not only to economize wire, but to prevent them from being dragged from the hands of the person who fired them.

This method was also abandoned subsequently, having the means of firing each mine by a separate battery, as will be described hereafter.

There were three voltaic batteries available for the Seaford explosion. The two principal ones were exactly similar, being both after Grove's construction.

1185.



Plan of the top of the Cliff, showing Battery House, and the situation of the three Mines above, and also the Conducting Wires leading from them, as well as the large Mine below to the Battery Shed.

Grove's consisted of five cells each, and by reference to the figures the description will be better understood, Figs. 1186 to 1188. The description need not extend further than for one cell, as the others were similar. The positive metal was zinc, and the negative platinum: two zinc plates 9 in. by 7 in., and the platinum 9 in. by 6 in. Sulphuric acid diluted in the proportion of one measure of acid to eight of water, and concentrated nitric acid, were the elements for generating the electricity. The zinc plates were amalgamated, and placed in a porcelain cell with the diluted sulphuric acid; between the two plates was inserted a cell of porous earthenware filled with nitric acid, and in this was immersed the platinum, which was attached to a bar of wood, the wood being rather thicker than the exterior breadth of the porous cell; a clamp of brass, as shown in the enlarged sketch, firmly received the two zinc plates, and secured them against the wooden bar; the connection of the zinc of one cell to the platinum of the adjacent one being made by slips of copper, as shown in Fig. 1188.

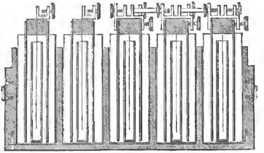
This form of battery was very convenient, as it could be charged without difficulty and be arranged for firing by two people in ten minutes; and those in the habit of using it could prepare it in six or seven minutes. It was also a very constant intensity battery, for at the end of five or six hours, which was the longest time the battery was ever kept in action here, it was in full strength. The same acid has been repeatedly used for charging the battery for a period of twenty hours, with simply adding a little water to the sulphuric acid solution, and up to that period no diminution in its strength has been discovered.

Grove's battery, of the before-mentioned size, is capable of firing one charge at a distance of 600 yds., or through a circuit of 1200 yds.; it will fire two charges simultaneously, arranging them as was originally proposed for the larger mines at Seaford, through a circuit of 1000 yds., the conducting copper wire being $\frac{1}{8}$ in. in diameter, and the platinum wire in the bursting charges $\frac{3}{8}$ in. long.

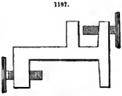
The porous earthenware cells, though they have been frequently used, are as good as at first.

The method of preserving them (as practised here) is, after the battery is taken to pieces, to soak them in a tub of water for half an hour, thus removing most of the nitric acid and metallic salt that may be in the pores, and then put them in some fresh water for an hour or so longer; the sulphate of zinc being soluble in water, is removed by this means.

1186.

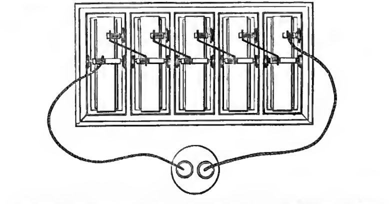


1187.



Elevation of Clamp.

1188.



The outer porcelain cells may be made of gutta-percha, which, however, though answering every purpose and not being fragile, would require a little care to keep them free from strong nitric acid; the dilute solution of sulphuric acid used has no effect on them.

This battery has many advantages: its connections are very simple, and easily cleaned, which are very essential points with a Grove's battery, for the nitric acid fumes will attack *brass*, *copper*, *solder*, and all such metals as are within the range of its influence. It is very constant in its power on different days, for whatever intensity it has shown on one occasion may always be confidently expected from it on another. With Daniell's battery this is not the case, the temperature having a great effect upon it, and the ox-gullet especially.

The third voltaic battery was of Smee's construction; it was in charge at Portsmouth, and, therefore, was made use of for firing one of the small mines above, as it is not generally adapted for firing charges at great distances: it will not be necessary to describe it minutely. The positive metal was zinc, amalgamated; and the negative, platinized silver; the exciting fluid was dilute sulphuric acid, one measure of acid to eight of water being generally used. It had twelve cells, and was very easily charged for use.

The conducting wire was composed of three strands of copper wire, $\frac{1}{16}$ in. in diameter, twisted as a rope, and then covered with tape, and a solution of shellac and varnish over that again. The advantage of twisting the wire thus is, that it is less liable to fracture, and is more flexible. A single strand of wire, having the same weight the yard, would convey electricity equally well, but

would soon get hard and unmanageable; it is very apt to break at bendings, and so break the circuit; twisted rope wire has a better chance, for one or even two strands may break, and the third be still left to complete the circuit. There was also used copper wire of single strand $\frac{1}{8}$ and $\frac{1}{4}$ in. in diameter.

Bursting Charges.—Those for the large mines below were 9 in. long, and cylinders 2 in. in diameter; and for the smaller mines about 6 in. long. They were lodged in the middle of the mine, and connected with the main conducting wire, which was brought through a piece of wood placed across the entrance of the chamber, and so jammed into it as to prevent the charges being dragged from their position.

By way of precaution, two charges were placed in each large mine, and connected with separate conducting wires, in case one pair might be damaged in tamping. The length of platinum wire for these bursting charges was different for those in each mine, one being $\frac{3}{8}$ in. long, and the other $\frac{5}{8}$ in.

It was doubtful, at the time when these charges were placed, by what method the mines would be fired. The short length of wire had been found quite sufficient for exploding charges, and it was intended to have used that if both mines had been fired by one battery; but as subsequently each mine was fired by a separate one, the bursting charges having the longer wire were attached to the main conducting wires at the mouth of the gallery, as giving a larger spark. However, either set of charges might have been used for either method with perfect success.

The twisted conducting wire, of which there were only 500 yds. available, was kept for such parts as were likely to come under the observation and close inspection of the spectators; for instance, from the battery house to the edge of the cliff, and to the top of the three shafts. That down the face of the cliff and the shafts was the single strand of thick wire before described, and covered with coarse canvas and pitch, tempered with tallow hastily made up. From the mouth of the gallery to the bursting charges below, the same thick wire was used bare, in this way:—A piece of deal, 3 in. broad, had two plough grooves run down it, in which one wire from each bursting charge of one mine was placed, and a fillet nailed over it, previously tarred. Another similar piece of deal had the other wires from these bursting charges fixed in it; these two were kept on *different* sides of the *branch*, and brought down the *main* gallery on *one* side. The same was done with the conducting wires from the other mine, which were brought down the *other* side of the main gallery, Fig. 1184.

The wires proceeding from the battery house were passed over the edge of the cliff through two double blocks, that were run out on two poles. The poles were placed about 10 ft. apart, on the ground, and projected over sufficiently to enable the wires to clear the face of the cliff. One wire from each mine was run through each double block; thus the pair belonging to each mine were kept 10 ft. apart down the face to the entrance gallery, where they were attached by soldering to those from their respective bursting charges: previous to soldering on these wires to those leading to the mines, the continuity of the circuit was tested by a galvanometer; and as every one was complete, the charge having $\frac{5}{8}$ in. platinum wire was selected for the purpose of firing. One Grove's battery was devoted to each large mine.

The three small mines above, each charged with 600 lbs. of powder, had each a battery to fire them, the two extreme ones by the two Grove's, and the centre one by the Smee's already alluded to. The wires were brought from the shafts into the battery house. The arrangement for firing was made as sketched in Figs. 1189 to 1191. M, M, M, M, are mercury cups into which the poles of the Grove's battery were plunged.

The operators stood with their backs to the cliff, facing their respective batteries, the mercury cups being between them and the batteries.

W_1 and W_2 represent two wires, one proceeding from one large mine below, and the small one above on that side. W_3 and W_4 represent two others, one proceeding from the other large mine below, and the small one on the side above. W_5 represents the wire from the centre mine above.

W_1', W_2', W_3', W_4', W_5', are those corresponding to W_1, W_2, W_3, W_4, W_5, that is, leading to the same mines.

1189. GROVE. 1190. SMEE. 1191. GROVE.

The orders for firing the mines were to explode the large ones first, and when it was known that they had gone off, the three small ones were to be fired. On the word to make ready, W_1, W_2, W_3, W_4, were inserted in their respective mercury cups, as shown in Figs. 1189 to 1191; and W_5 was attached to the binding-screw of one terminal pole of the Smee's battery.

W_1', W_2', were held by the officer in charge of that battery, one wire in each hand. W_3', W_4', were similarly held by the officer over that battery, and W_5' was in Lieut. Crossman's charge.

Captain Frome arranged to give the signal thus:—"One, two, three, *fire*," and "One, two, three, *fire*;" the first fire referring to the large mines (when the wires leading to those were to be plunged into the other mercury cups), and the second fire to the three small mines (when all three officers had to complete the circuits corresponding to those). At the first word fire, the two large mines exploded, and the effect produced separated the cliff behind the three smaller mines so quickly as to drag all the remaining wires out of the window, thus preventing the upper ones from being fired. The wire W_5, attached to the binding-screw of Smee's battery, pulled it over, and the shock made the other batteries jump on the table, mixing and spilling the acids.

With respect to the plan originally proposed for firing the mines below, namely, by one battery, and placing the charges in one continuous circuit, it was asserted to be an uncertain method; because, if one platina wire was a little shorter than the other, the short one would fire first, and, thus disconnecting the circuit, would prevent the other from exploding.

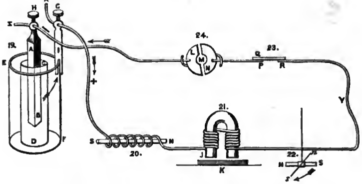
Subsequent experiments (as has been before stated) have proved this opinion erroneous, for in all trials that have been made at Portsmouth of that method of firing, the length of platina wire was always judged by the eye, *never* accurately measured. But a safe means could have been adopted to prevent even this contingency, and have placed beyond possibility the chance of only one charge exploding. The diagram, Fig. 1192, will explain it.

1192.

The dotted lines represent the copper conducting wires leading to charges C_1 and C_2. The length of platinum wire in C_1 may be made $\frac{5}{8}$ in. long, that in C_2 $\frac{7}{8}$ in.; and at points *a* and *b* connect copper wires of the same thickness as the conducting wires, leading towards each other, but not approaching nearer than 1 in., and this interval connected by soldering on a platina wire 1 in. long, between the two, and encasing it in wood to protect it from possible fracture in the tamping, and securing it from all strain. On completing the circuit at the battery, C_1 would fuse before C_2, being $\frac{1}{4}$ in. shorter, but the electric circuit through C_2 would still be complete by the aid of the connections *a b*; similarly, C_2 must fuse before the platina wire at *a b*, being shorter by $\frac{1}{8}$ of an in.; and the interval between the explosion of C_1 and C_2 would not be more than $\frac{1}{6}$ of a second at the most; indeed, practically, instantaneous.

Application of Permanent Magnets to the Explosion of Mines and Submarine Charges.—Electro-magnetism and magneto-electricity may be explained and illustrated as follows: A cell of Daniell's battery is represented in Fig. 1193; a rod of zinc A B is placed within a tube C D of porous earthen-

1193.

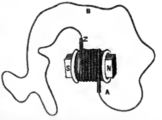


ware, the vessel E F being of copper. The porous tube C D, containing the zinc rod A B, is filled with a mixture of one part sulphuric acid and ten parts water; the space between the earthenware tube and the copper cell E F is filled with a saturated solution of sulphate of copper; this saturated solution is prepared by pouring boiling water on a superabundance of crystals of sulphate of copper and stirring them; to this solution one-tenth acid should be added. A binding-screw H establishes metallic contact between the zinc rod A B and one end of a wire, the metals being clean at the points of contact; the other end of the wire is brought into metallic contact with the copper cell E F by means of the binding-screw G and the metal support I, which may be either of brass or copper.

In the coil of insulated copper wire at 20, when the positive galvanic current descends and passes in a right-handed spiral round the soft iron bar N S, 20, the iron bar becomes an electro-magnet, the north pole N on the right of the observer. The bar of soft iron N S loses its magnetism or becomes demagnetized the instant the continuous metallic circuit X, 20, 21, V, M Z is broken. Suppose the wire to be made fast to two metal discs L and N, 24, which do not touch, then the galvanic current will not circulate as the continuous metallic contact is broken; but the instant a plug of metal, touching both the discs, is placed in the hole M, the galvanic current circulates, and S N, 20, will be found to acquire a considerable quantity of magnetism, the cell 19 being charged and arranged as before directed. But as soon as the plug M is withdrawn, or the metal bar Q, 23, removed, the circuit is broken, and the bar S N, 20, loses its magnetism. The bar Q, 23, establishes metallic contact between the ends P, R, of the wire. *It must be observed by those who are not acquainted with galvanic electricity and technical terms that positive electricity passes from the lower part of the zinc rod through the fluids and porous pot* C D, *to the copper cover* E F, *and then continues its course* X, +, 20, 21, 22, V, 23, *the plug* M, *and returns to the upper end* H *of the zinc bar.* The electric current passes from the *zinc* to the *copper* through the porous pot and fluids, and leaves the battery by the wire (which may be of immense length) attached to the copper, passing through any apparatus that maintains continuous metallic contact, and returning to the battery by the wire attached to the end of the zinc which is not immersed in the fluid; the copper, although the negative metal, forms in this case the *positive end* (+) of the battery; and the zinc, although the positive metal, forms the *negative end* (−). A piece of soft iron, 21, when bent in

the form of a horse-shoe, round the horns of which is wound spirally a length of well-insulated copper wire, acquires a considerable quantity of magnetism while a galvanic current is passing through the wire; one end of the magnet so arranged becomes the north pole and the other the south, if the spiral be wound in the same direction throughout, supposing the horse-shoe to be unbent and made straight. When a galvanic current circulates round the horns of a horse-shoe electro-magnet 21, a piece of soft iron K, near its ends or poles, will be raised; but as soon as the plug of metal M, which is technically termed a contact-peg, is removed, the electro-magnet 21 becomes demagnetized, and K is disengaged or allowed to fall. Electro-magnets of the form 21 have been arranged so that they sustained a weight nearly equal to a ton. If a positive galvanic current passes along a wire in the neighbourhood of a magnetic needle N S, 22, the needle will be deflected, and will take a position *n s*, Fig. 1193, at nearly right angles to the wire. But when the circuit is broken by withdrawing the contact-peg M, or by removing the strip of metal S, 23, the magnetic needle will return to its original position N S. The Danish philosopher Oersted, about the year 1820, discovered the connection between galvanism and magnetism; he also illustrated his discovery by many phenomenal developments. In applying electro-magnetism to the business of telegraphy, the next important discovery was made by Steinheil, who found that the earth might be used to make up half the circuit of a galvanic current; for if a number of cells like 19 be combined, so that the battery may be of sufficient strength, the discs of metal M, N, 24, Fig. 1193, may be buried in the earth at a great distance apart, and yet the circuit will be complete although the return wire is dispensed with. Faraday found by experiment that the converse phenomena also takes place, namely, that on inserting a permanent magnet N S, Fig. 1194, into the middle of a helix of insulated wire A Z, a current of electricity is generated in the circuit of wire A B Z; the direction of the current depending upon the pole inserted and the end of the spiral with respect to the direction of its windings.

1194.

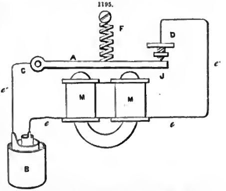


This experiment of Faraday has been much overrated, for, when Oërsted had discovered that an electric current produced a magnet, it required but little analytical skill to observe that the converse phenomena takes place, namely, that a magnet would produce an electric current.

Many vague conjectures and absurd theories were entertained about the mechanical action of the galvanic and electro-magnetic currents until Ohm, a German physicist, proved that $I = \frac{F}{W}$, in which F = the electric motive force, W = the resistance, and I = the intensity. Faraday proved experimentally that $Q = s\,I$, Q being the quantity of electricity conveyed by the current, I the intensity, and s = the time during which the current circulates. Dr. Joule asserts, following out the ideas of Dr. Mayer, that $U = I^2\,W\,s$; in which U = units of work. However, the proofs by which our present mechanical equivalent of heat has been established are far from being satisfactory. This experimental proposition of Mayer and its converse may or may not be true. The proofs given by Professor Tyndall and Dr. Joule are not conclusive. Many forms of battery, a variety of mechanical contrivances, and numerous formulæ, have been employed in the business of telegraphy, the most useful of which we give elsewhere, in order of merit. But those developments, except the local battery of Morse, are of a very second-rate character compared with those we have enumerated.

To illustrate what we have stated with respect to the electro-magnet, we will explain the simple principle upon which W. Siemens constructed one of his first telegraphs. Suppose A J, Fig. 1195, to be a piece of soft iron, supported on an axis C at one end, and lifted by a spring F in the middle, so as to press A J upwards against the metallic contact-screw D. Let the positive pole of the battery B be connected by a wire e with one end of the wire-coil of an electro-magnet M M, the other end of the coil being connected with the contact-screw D, by a wire e'; while a third wire e'' completes the circuit; e'' connects the negative pole of the battery with C the axis of the piece of soft iron or armature A J. When the circuit is complete, the current circulates in the coils of the electro-magnet M M, magnetizes them, and causes the soft iron lever A J to be attracted to the poles; this operation breaks the metallic contact between the lever C J and the contact-pin D. When this occurs, the galvanic current ceases to circulate in the coils of M M, the soft iron cores of which become demagnetized, and have no longer the power to retain C J, which is therefore lifted by the spring F. But then contact is again established between D and

1195.



C J, and the galvanic circuit again completed. So that when the apparatus is properly adjusted, the soft iron lever A J will continue to move up and down as long as the battery and the mechanical arrangement remain in working order. One galvanic circuit may be arranged to give motion to two or more such levers as A J at the same time, which motions may be applied to move pointers on dial-plates and convey telegraphic messages.

Magnetism, or the property of permanent polarity, was formerly supposed to belong to iron only. Later researches show that this is to be shared, though not equally, with nickel, cobalt, and chromium. Occasional magnetism may be excited in most substances, as is shown by their influencing the oscillations of a freely-suspended magnetic needle. But this influence is much weaker in all other substances than in the four which we have named. *Silver*, which stands the highest of all the other metals, is nine times feebler in this respect than iron; *gold* fifteen times, and marble nearly twenty times more weak. Iron acquires magnetism by contact or suitable friction with a magnet, by being suitably rubbed or struck in a proper position, by exposure to refracted light of the sun, and even by being left to stand in a nearly vertical position. Here it is enough to say that, owing to the ease with which it is accidentally developed, it is extremely difficult to find in the shop of a philosophical instrument maker, for instance, a tool or strip of iron which is not in some degree magnetic. In all its conditions and states it is susceptible of this property, but develops it differently in each. Thus, grey crude iron becomes sooner and more intensely magnetic than white iron, but yields in both these regards to wrought iron and steel. Soft ductile iron is more easily and more strongly magnetizable than steel, but does not retain its magnetism as well. A similar relation is observable between untempered and tempered steel. The magnetism of iron may be weakened or lost by methods similar to those which originally impressed it. The filings of a magnet are less magnetic than the solid mass. A heavy sudden blow or shock against a hard body will sometimes destroy magnetism. Heat always diminishes it; although there are some peculiarities which have been observed in this regard that are difficult of explanation. It undergoes deterioration whenever similar poles of two equally strong magnets are kept in prolonged contact; and, finally, is always abated by alloying with other substances, and may be destroyed entirely by increasing the proportion of alloy. Arsenic is, in this respect, the most active of the metals, though an alloy of two-thirds arsenic does not entirely prevent the mass from being attracted by the needle. Mushet, however, affirms that 22 per cent. of manganese effectually destroys magnetism in an alloy of iron. Malleable iron is an excellent conductor of *electricity*; and although in this respect inferior to copper and zinc among the easily oxidized metals, and to gold, silver, and platinum among the others, it is yet, for economy, universally employed for telegraphic purposes and for lightning-rods. In the voltaic pile it follows zinc in the order of electro-positive metals. The *electro-magnetic* properties of iron are very remarkable, in the facility with which it is converted into a magnet of great energy during the passage through it of a galvanic or electric current. It is on this that the electro-magnetic telegraph owes, in part, its adaptation and success.

The ignition of gunpowder by the direct magneto-electric current, though well known to be practicable, had, in 1861, never been applied to military or industrial operations in England, and no satisfactory experiments showing its practical applicability to these purposes had been published.

In the first experiments of Abel and Wheatstone a powerful magneto-electric machine constructed by Henley was used.

A few trials sufficed to show that, even with this instrument, gunpowder itself could not be ignited with any degree of certainty. Results obtained with Statham's and other fuzes, though superior to those furnished by gunpowder alone, were still far from satisfactory.

The first experiments were, therefore, directed to the discovery of a suitable agent to serve as a perfectly certain medium or priming material for effecting the ignition of charges by means of the magneto-electric machine. For this purpose a variety of compositions of a more or less sensitive character were prepared for trial with the magnet.

Many of these compositions furnished results to a certain extent favourable: a number of fuzes, primed with them, having been fired in succession with the magnet, and from two to four charges in one circuit having been ignited in a very few instances. But no perfect certainty of discharge was attained with any one of the materials, the attempt to fire a fuze being frequently unsuccessful; while no difference between it and a successful fuze containing the same composition could be detected by careful examination.

These preliminary trials, however, established the fact that the sensitiveness or ready explosiveness, of a priming material was not alone sufficient to determine its success, but that those which possessed a certain, though not too considerable, degree of conducting power, were more readily and certainly ignited than others of a far more sensitive character.

Some successful results obtained accidentally with one of the experimental compositions, which had become damp by exposure to the air, led to a trial of the effect of moisture in promoting the ignition of but slightly sensitive compositions; and it was ultimately found that the impregnation of ordinary gunpowder with a small amount of moisture, by an expedient similar in principle to one adopted with considerable success by Capt. H. Scott, in connection with charges to be fired by the induction-coil machine, rendered its ignition by means of the magnet a matter of certainty.

Some important precautions were, however, indispensable to the attainment of this definite result. If the slightly damp powder were employed in a finely divided condition, it very frequently became caked between the wire terminals in the fuze, and the current would then pass through the composition without igniting it. This was found to take place occasionally, even when the powder was employed in its original granular condition. Several attempts were made to overcome this difficulty by modifying the form and position of the terminals; and an arrangement of a completely successful nature was eventually contrived, in which only the sectional surfaces of the extremities of the terminals, which consisted of fine copper wire, $\frac{1}{16}$ in. diameter, were exposed in the interior of the fuze so as not to project at all. The prepared gunpowder, therefore, simply

rested upon the surfaces, and a perfect uniformity in the action of the fuze was attained. The priming composition consisted of fine-grain gunpowder, which had been soaked in an alcoholic solution of chloride of calcium, of a strength sufficient to impregnate the grains with from 1 to 2 per cent. of that salt. The prepared powder was exposed to the air for a short time, to permit of a sufficient absorption of moisture by the deliquescent salt.

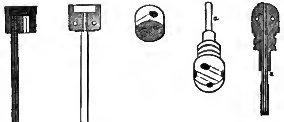
Upwards of 500 quill fuzes, of the description employed for firing guns, primed with the prepared gunpowder and fitted with the arrangement of the terminals above referred to, were fired with the large lever-magnet. The failures did not amount to more than 3 per cent., and were all proved to be due to defective manufacture.

This fuze was found to be easy of manufacture and permanently effective. While, however, it presented a certain means of effecting the ignition, by the aid of a powerful magnet, of single charges, or of a large number to be fired in moderately rapid succession, it was inapplicable to the ignition, with certainty, of more than one charge in circuit.

A new description of priming material for the fuze was prepared soon afterwards, which greatly exceeded in sensitiveness any of the other compositions hitherto tried. A very gradual separation of the armature from the large magnet sufficed to effect the ignition of the fuzes primed with this material, and the induced current obtained by means of a very small magnet, with a rotatory armature, such as that employed in Wheatstone's magneto-electric telegraph, was sufficiently powerful to produce the same result.

The fuze-head, which is of box-wood, contains three perforations, Figs. 1196 to 1198; the one passing downwards through the centre receives about 2 in. of double insulated wire *a a*, Figs. 1199, 1200, two copper wires of 24-gauge, 0·022 in. diameter, enclosed side by side, at a distance of

1196. 1197. 1198. 1199. 1200.

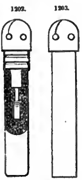


$\frac{1}{16}$ in., in a coating of gutta-percha of $\frac{1}{4}$ in. diameter; the other two perforations, which are parallel to each other on each side of the central one, and at right angles to it, serve for the reception of the circuit wires. The arrangement for securing the connection of these with the insulated wires in the fuzes is as follows:—

The piece of double covered wire above referred to is originally of a sufficient length to allow of the gutta-percha being removed from about $1\frac{1}{2}$ in. of the wires. These bare ends of the fine wires, which are made to protrude from the top of the fuze-head, are then pressed into slight grooves in the wood, provided for their protection, and the extremity of each is passed into one of the horizontal perforations in the head, in which position it is afterwards fixed by the introduction into the hole of a tightly-fitting piece of copper tube, so that the wire is firmly wedged between the wood and the exterior of this tube, and is thus at the same time brought into close contact with a comparatively large surface of metal. It will be seen that it is only necessary to fix one of the circuit wires into each of these tubes, in the opposite sides of the fuze-head, in order to ensure a sufficient and perfectly distinct connection of each one of them with one of the insulated wires in the fuze.

1201.

1202. 1203.



The extremity of the double covered wire, which protrudes to a distance of about $\frac{3}{8}$ of an in. from the bottom of the fuze-head, is provided with a clean sectional surface by being cut with a pair of sharp scissors, care being taken that the extremities of the fine copper wires are not pressed into contact by this operation.

A small cap of about $\frac{1}{4}$ an in. in length is then constructed of thick tin-foil, Figs. 1199, 1201, into which is dropped about 1 grain of the priming material. The double wire is then inserted, and pressed firmly down into the cap, so that the explosive mixture is slightly compressed and in close contact with the surfaces of the wire terminals.

The cap is fixed by winding a piece of twine once or twice round its upper part, tightening the ends of this, and then removing it. The actual fuze is then ready for enclosure in a small charge of gunpowder, Figs. 1202, 1203. The powder is contained in a paper case tied on to the head, or in a cylinder of sheet tin, tightly fitting on the fuze-head at one end; the other, after the introduction of the powder, being closed with a plug of clay or plaster of Paris.

It is advisable to have the fuzes ready fitted with pieces of insulated wire about 2 ft.

in length, twisted together as shown in Fig. 1205. The ends of the wires, after they are passed through the connecting holes in the fuze-head, should be tightly fixed in their position by the introduction of a short piece of copper wire.

1204.

1205.

The phosphide of copper fuze for firing cannon, Fig. 1204, differs slightly in its construction from the mining fuze. The fuze-head is longer than in the latter, and of such a form that the double covered wires, which are fitted into it in the manner already described, are completely enclosed in it, the lower extremity of its central perforation still remaining free to receive the top of the quill or copper tube charged with powder, like the ordinary tube arrangement for firing cannon.

The priming material contained in the fuze is prepared by reducing separately to the finest possible state of division the sub-phosphide of copper, sub-sulphide of copper, and chlorate of potassa, and then mixing these powdered substances very intimately, in the proportions of 10 parts of the first, 45 of the second, and 15 parts of the third, by rubbing them well together in a mortar, with the addition of sufficient alcohol to thoroughly moisten the mass. The mixture is afterwards carefully dried, and may be safely preserved in closed vessels until required.

In the experiments subsequently carried on with fuzes which contained this composition, it was found that a slight residue, consisting principally of the coke employed, occasionally remained on the surfaces of the terminals in the fuze after its discharge, and, by forming a good conducting link between them, interfered with any further effects of the magnetic current in other directions, by the establishment of a complete circuit.

The obstacle to the complete success of the composition was entirely removed by the substitution of another material, more easily acted on by the chlorate of potassa than the coke, and answering equally well with the latter as a conducting medium, namely, the sub-sulphide of copper.

No instance has occurred in the discharge of several thousand fuzes, primed with the mixture of sub-phosphide and sub-sulphide of copper with chlorate of potassa, in which the terminals have not been found quite free from adherent residue after the ignition.

The sub-phosphide of copper, which is produced at an elevated temperature, is a compound of very stable character, and the mixture of the three constituents is quite as unalterable as the explosive mixtures which are in general use for the preparation of percussion caps, and so on. The stability of the mixture has been submitted to very satisfactory tests. Fuzes primed with it have lost none of their delicacy and certainty when tried more than two years after preparation. See Atomic Weights, p. 195.

The sub-phosphide of copper, intimately blended with chlorate of potassa, forms a mixture in a high degree sensitive to the effect of heat, and possessed at the same time of some power of conducting electricity. With the employment, however, of magneto-electric machines of comparatively low power, and in cases where the resistance to be overcome by the current is considerable, this conducting property is not sufficient to ensure the ignition of the mixture by assisting the passage of the current across the interruption in the metallic circuit—across the small distance between the terminals of the wires in the fuze. It must be borne in mind that the striking distance, or the space between the terminals, across which the current from even a powerful magneto-electric machine will leap, is very small. With the large lever-magnet the spark could only be produced when the wires were almost in contact. Since, however, it is indispensable to the proper insulation of the wires in the fuze arrangement that the terminals should be at least $\frac{1}{8}$ of an in. apart, it will be readily understood how essential to success in operations with these machines it is that the priming material should possess considerable conducting power. Hence the necessity of increasing the conducting power of the mixture of sub-phosphide of copper and chlorate of potassa; a result which it has been already stated was attained in the first instance by the employment of finely powdered coke, and afterwards by the substitution of sub-sulphide of copper for that substance.

Many experiments were of course required to determine the proportions in which it was advisable to employ the conducting constituent, so as to facilitate the passage of the current through the mass as far as possible, without interfering too much with the sensitiveness of the explosive mixture, or producing an almost perfectly continuous connection between the two poles in the fuze, and thus promoting the passage of the current so greatly as to prevent the ignition of the composition.

Considerable difficulties were encountered in the endeavours properly to balance these conditions, when attempts were made, which will presently be mentioned, to apply the mixture in question to the ignition of several charges in circuit. The increase in the resistance of the current, consequent on the introduction of more than one interruption in the metallic circuit, necessitated an increase in the conducting power of the mixture, which it was difficult to attain, unless at a considerable sacrifice of the sensitiveness of the composition.

It was consequently found that when the proper conditions had been attained for ensuring the passage of the current through several—five or six—fuzes in circuit, the absolute certainty of the fuze, when applied in this manner, had been sacrificed. Thus, out of several fuzes tried together, which had been most carefully prepared, so as to be as far as possible perfectly alike, the current would ignite a few, passing through the others without affecting them, and would thus point to

minute differences in the conducting powers and sensitiveness of different portions of one and the same quantity of the mixture, which was prepared in such a way as to ensure the greatest possible uniformity.

The results of many experiments established the fact, that the proportions of ingredients already referred to furnished a mixture possessed of the highest conducting power attainable without detriment to the sensitiveness or ready explosiveness of the material. The certainty of its action, when applied in the fuze, to the explosion of a single charge, by employing a permanent magnet instead of a battery to establish the current, has been proved by the ignition of several fuzes, without failure. See Figs. 1193, 1194.

Experiments, made with the aid of this composition, established the fact that the current obtained by means even of a very powerful permanent magnet, when applied to the ignition of several charges arranged in succession in one circuit, is very limited in its powers. In illustration of this it may be stated that, on trial being made of twenty-one consecutive sets of four charges, eighteen of the sets were perfectly discharged; but, in the other three sets, only two or three of the charges were ignited. Out of five sets, of five charges each, only two sets were completely discharged; and in several attempts made to ignite six fuzes in one circuit, only four were fired in each case. In all these experiments, when charges had escaped ignition, the current had passed through the sensitive composition without firing it. When the discharged fuzes were removed, and the remaining ones properly connected, they were all fired.

It has been already stated that no beneficial effects were attained by modifying the proportions or ingredients in the priming composition, so as to diminish or increase its conducting power.

Three charges were therefore the most that could be ignited *with certainty* by means of a powerful electro-magnetic machine, when they were arranged in succession in simple circuit.

The plan, originally suggested by M. Savare, of arranging the charges in divided circuits, was next tried, and furnished far more successful results. The simultaneous ignition of twenty-five charges was repeatedly effected by means of the large magnet, each charge being connected with a separate branch attached to the main line, which led from one pole of the magnet, and their connection with the earth established by means of uncovered copper wire, the extremity of which was wound round an iron stake driven into the ground.

A still larger number of charges (forty) was similarly exploded on several occasions.

These results were all obtained with the large magnet, the current being established by rapidly separating the armature from the poles by means of a lever. By a simple arrangement for shifting the connection of the main wire with the exploded charges, from them to a second series, similarly arranged, twenty-five were also simultaneously ignited, on allowing the armature to return to the poles of the magnet. It was found, moreover, that the same number could be fired by means of this magnet, even if two folds of thick brown paper were interposed between the poles and the armature, so that on depression of the lever the armature had no longer to be forcibly detached, but simply to be removed from the magnet.

These successful results led to trials of magneto-electric machines of comparatively small size, with revolving armatures. In the employment of these machines, it was of course not expected that any single induced current obtained from them should distribute itself among a number of fuzes placed in divided circuit, as was the case with the comparatively much more powerful current obtained with the large magnet; but it was hoped that the very rapid succession of currents furnished by them would produce a very similar result, by distributing themselves over the different branches of the circuit with which the fuzes were connected, and that the ignition of the whole of the fuzes, though it could not be so positively instantaneous as when the one current was discharging the entire number, might yet be effected with such rapidity as practically to amount to a simultaneous discharge.

The results obtained fully confirm these expectations. With a small horse-shoe magnet, 7 in. in length, 1 in. in breadth, and 1¾ in. in thickness, provided with a revolving armature and multiplying wheels, by which great rapidity of motion could be attained, twenty-five charges were fired; the effect of the discharge on the ear was, however, not like that of one single explosion, as was the case in the former experiments, but like that of an exceedingly rapid volley, in which the explosion of any single charge could not be distinguished.

Still more favourable results were obtained with a very compact arrangement of six magnets, each about half the size of the above, devised by C. Wheatstone, for the production of an extremely rapid succession of currents, established in such a manner that the effect would be almost equal to a continuous current.

It consisted of six small magnets, to the poles of which were fixed soft iron bars surrounded by coils of insulated wire. The coils of all the magnets were united together, so as to form, with the external conducting wire and the earth, a single circuit. An axis carried six soft iron armatures in succession before each of the coils. By this arrangement two advantages were gained; all the magnets simultaneously charged the wire, and produced the effect of a single magnet of more than six times the dimensions, and at the same time six shocks or currents were generated during a single revolution of the axis, so that, when aided by a multiplying motion applied to the axis, a very rapid succession of powerful currents was produced. A single large magnet with a rotating armature could not be made to produce the same succession of currents without the application of considerable mechanical power. Another peculiarity of this apparatus was that the coils were stationary, and the soft armatures alone were in motion; by this disposition the circuit during the action of the machine was never broken. In the usual magneto-electric machines with rotating armatures the circuit is necessarily broken twice during every revolution, and this frequently gives rise to irregularities in the production of the currents. By the construction adopted, the currents can never fail to traverse the circuit. It must be borne in mind that our account of this investigation is taken, with some alterations, from an inflated report to the Secretary of State for War,

by Wheatstone and Abel. Such documents are generally cooked up. See 'Professional Papers of the C.R.E.,' vol. x.

The total weight of the instrument, enclosed in a case, was 32 lbs. 11 oz. It was enclosed for transport in a small packing-case, weighing about 7 lbs.

The system of firing charges by means of magneto-electricity, with the aid of the phosphide of copper fuze, having been thus far successfully developed, a series of experiments was instituted on it at Chatham, for the purpose of thoroughly testing its certainty and applicability in the field, and subsequently for ascertaining the extent to which it admitted of application to the explosion of submarine charges. These experiments extended over a period of six months, and were performed under various conditions of weather.

The magnetic apparatus employed in all the field experiments was so arranged that the whole apparatus was enclosed in a box, the only exposed portions being the binding-screws for the attachment of the wires, a handle for setting the armatures in motion, and a key, by the depression of which, at a given signal, the circuit could be completed.

To employ the instrument at any moment, the following were the operations necessary:—

The insulated wire and the copper wire passing to the earth (the earth taking the place of the return wire) were fixed to the apparatus by means of the binding-screws; the instrument was raised from the ground by being placed on its packing-case; at that height a man could operate with it when in the kneeling posture.

At a signal ready, the handle was turned with one hand, so as to cause the armatures to revolve with the greatest possible velocity; whilst the other hand was pressed against one corner of the instrument, close to the key, so as to steady the box, and to be ready at the signal fire to depress the key with the thumb.

The connection of the instrument with the earth was effected as follows:—

A moderately clean spade was selected from among those used by the men in digging holes for the charges. One end of a piece of stout copper wire was placed under the edge of the spade, in such a manner that when the latter was firmly forced into the ground it was pressed by the earth on both sides against the iron surface. The protruding wire was wound once or twice round the bottom of the spade-handle, and then attached to the binding-screw of the permanent magnet.

The gutta-percha-covered wire used in the experiments having been in occasional service at Chatham for some years, the coating had sustained some injury in two or three places. Such defects were protected from possible contact with the earth by means of waterproof cloth or sheet india-rubber. The total length of wire used was 881 yds., of which 600 were extended, lying along the ground.

To the extremity of the covered wire a number (from 12 to 25) of pieces of similar insulated wire, varying in length between 3 and 6 yds., and serving to connect it with the individual charges, were attached in the following manner:—About 6 in. of the extremity of the main wire and of each of the branch wires were laid bare, and cleansed; the end of the former was then surrounded with those of the latter, placed in an opposite direction, and the whole tightly twisted together by means of pliers, so as to be brought thoroughly into metallic contact with each other and with the main wire. The twisted wires were then bound round with moderately fine copper wire, which was made to bring every portion of the exterior of the bundle into connection. The joint was made rigid with pieces of stick tied against it, and the whole securely enveloped in a piece of waterproof cloth or canvas, to protect it from damp and contact with the earth.

These connections, though of a very rough description, and most readily prepared by any soldier, were thoroughly effectual. No instance occurred in the whole of the experiments of the failure of a charge which could be attributed to an imperfect metallic connection of its branch wire with the main wire.

The following was the method adopted for connecting the fuzes with their respective branch wires and with the earth:—

The fuzes, as they were manufactured, were always fitted, as shown in Fig. 1205, with two pieces of covered wire twisted together. They were thus ready for insertion into the bag or other receptacle containing the charge of gunpowder, the ends of the covered wires protruding from the opening of the latter to a convenient distance for effecting the junction with the branch and earth wires, so that a complete galvanic circuit might be established, which was excited by the permanent magnet. The extremities of one of the other fuze-wires and of a branch wire, from both of which the gutta-percha was removed to a distance of about 2 in., were connected by hooking them firmly one in the other with pliers, in the manner shown in Fig. 1206. A piece of fine copper

1206.

binding wire, about 6 or 8 in. in length, was then twisted over the whole of the connection, and the joint was finally enclosed in a small wrapping of oiled canvas, in a manner similar to that adopted at the principal junction with the main wire.

The extremity of the other fuze-wire was attached to an uncovered copper wire of sufficient length to bring the whole of the charges into connection with each other in this manner. The wire was fixed in a convenient position by being twisted round short stakes or pickets driven into the ground, and its extremities were buried in the earth, being attached either to spades, as already described, or to zinc plates about 8 in. square.

With reference to the earth-connection, the employment of large metallic surfaces was also proved, by repeated experiments at Chatham and Woolwich, to be superfluous. The simple insertion into the ground of the uncovered extremities of the fuze-wires was found to afford a perfectly sufficient connection for ensuring the ignition of the charges.

The largest number of charges which it was attempted to fire at once at Chatham was twenty-five. The ignition of twelve charges was repeatedly effected, and with such rapidity as to have the practical effect of a simultaneous discharge of the whole. With twenty-five charges the interval between the first and last discharge was very decided, being certainly longer than when the same number of charges were fired at Woolwich with the employment of a greater length of wire, of which, however, the larger portion was coiled up, the space between the earth-connections being only about one-half of that introduced at Chatham; yet it was considered that even the ignition of the twenty-five charges, at a distance of 600 yds. from the magnet, and with the employment of 881 yds. of covered wire, and, in addition, about 100 yds. in the form of branch wires, was effected with sufficient rapidity to allow of that number being employed in cases where a simultaneous discharge was required.

Another instance of the apparent effect of increased resistance, in the form of an increase in the length of wire laid out, in diminishing the rapidity of discharge, was observed in the employment of one branch wire of four or five times the length of the others. A distinct interval was noted between the explosion of the other eleven charges and that of the one attached to the longer branch wire.

Experiments were made to ascertain whether, to complete the circuit, the employment of a second insulated wire, in the place of 600 yds. of earth-connection, would modify the rapidity of ignition of a number of charges, but no difference of effect was observed.

It need scarcely be stated that, in dealing with electricity produced by a permanent magnet, defects in the insulation of the main and branch wires had to be very carefully guarded against. Several failures in the first experiments were eventually traced to some defect of that kind. An instance even occurred, before the proper method of protecting the connections of the charges with the insulated wires was adopted, in which the deposition of moisture upon the gutta-percha-covered wire, near the charge, prevented the ignition of the latter, by forming a connecting link between the extremity of this wire, where it was exposed and attached to the fuze, and the uncovered wire leading to the earth, in consequence of the two wires being in contact at a distance of several inches from the fuze.

It is therefore always a preliminary precaution of primary importance that the insulating covering of the wire to be employed be carefully inspected while the latter is being laid out for use, and that any imperfections be protected from possible contact with the earth or from the access of moisture, a result readily attainable by the application of some waterproof envelope to the injured portion.

The experiments instituted at Chatham with the object of applying the current produced by a permanent magnet to the ignition of *submarine* charges were attended with greater difficulties than those which served to test the system in its application to land operations; nevertheless, the results ultimately attained were also of a character to lead to definite and favourable conclusions.

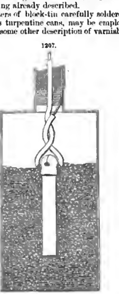
The method of establishing the connections of a charge with the wire and the earth differed naturally in some respects from the mode of proceeding already described.

The charges of powder were contained in canisters of block-tin carefully soldered so as to be water-tight. Any vessels of this material, such as turpentine cans, may be employed, provided they be perfectly coated inside with marine glue, or some other description of varnish.

The fuze, with two wires attached as before, the one a few inches longer than the other, was inserted into the charge, and fixed in its proper position in the canister by means of a loose-fitting bung, pushed a little distance into the neck, and cut on one side, so as to admit of the passage of the longer insulated wire, while the bare part of the shorter wire was firmly pressed by the cork against the inside of the neck. The latter was then completely filled up with melted gutta-percha, and the extremity of the short uncovered wire was bent back over its side, so as to be in close contact with the metal surface. In this manner the enclosed fuze was brought into good metallic connection with the wet earth or water by which the canister would be surrounded. See Fig. 1207.

The insulated wire projecting from the mouth of the canister was connected with one of the branch wires in the manner already described; but, in order thoroughly to protect the connection from the water in which it would become immersed, a piece of vulcanized india-rubber tubing of suitable length, and a tin tube rather longer and wider than the latter, were slipped on to the branch wire, before it was joined to the fuze-wire; and when the junction had been effected, the india-rubber tube was pulled over it, and tied very firmly at both ends on to the gutta-percha covering of the wires. See Fig. 1208.

1207.



1208.

A small quantity of cement, consisting of beeswax and turpentine, was rubbed in between the gutta-percha and the ends of the india-rubber tube, so as thoroughly to ensure the exclusion of

water; and finally the tin tube was pulled over the joint, and fixed by compressing the ends, for the purpose of imparting rigidity to the junction, and thus protecting it from injury by a sudden twist or strain. By these arrangements the perfect exclusion of water from the charge, and from its connection with the branch wire, was effected. In an equipment prepared for effecting submarine explosions, by means of an electric current established by a permanent magnet, in China, stout bags of vulcanized india-rubber were provided for the reception of the charges. These bags were fitted with sockets and screw-plugs of gun metal. The fuzes furnished for use with these bags were attached to two pieces of covered wire, about 18 in. long, which were enclosed side by side in a cylindrical plug of gutta-percha, Fig. 1209, about 4 in. long, and carefully made to form

1209.

one mass with the coating of the enclosed wires. This plug was made to fit pretty tightly into a thick washer of india-rubber contained in the socket of the bag. An inner screw-socket, which was brought to bear with great force upon a metal ring resting on this washer, when the plug had been inserted, compressed its internal surface against the latter in such a way as to ensure a perfectly water-tight joint.

The first trials of these charges were made in a shallow canal with a mud bottom, and from which at the time of experiment the water was receding so rapidly, that before the whole of the charges had been immersed several of them were left half-imbedded in the mud. Twenty-five charges were arranged, of which thirteen were exploded, though less rapidly than in the experiments on land. On the next occasion, when twenty-five charges were regularly surrounded by water, simply resting upon the firm bed of a pond of some depth, only four of the charges were exploded. Several other attempts were made to fire a small number of (ten and five) charges similarly immersed, but in every instance only four were ignited. A careful examination into the cause of the invariable explosion of so comparatively limited a number of charges under water led to the following explanation.

It will be remembered that the explosion of numerous charges in a divided circuit by the magneto-electric apparatus with revolving *armatures* is effected by the action of an exceedingly rapid succession of currents. The rapidity with which they follow each other, however great, cannot equal that with which the terminals of a fuze, exploded in a small charge under water, come into contact with the latter after the explosion. The instant this occurs a complete circuit is established through the water, and any further action of the currents is at once arrested.

By the time, therefore, that four charges had been ignited in extremely rapid succession, so as to be apparently exploded at once, a sufficient interval of time had in reality elapsed to allow the water to re-occupy the space filled for a brief period by the gaseous products of the first explosion, and thus to rush in upon and complete the circuit with the terminals of the fuze. The piece of soft iron K, when attracted by the temporary magnet 21, shown in Fig. 1193, is termed an armature.

It is believed that charges are generally so arranged for submarine operations as to be partially or completely surrounded by the objects upon which the force of the exploding charge is to be exerted, and that they are even at times firmly fixed in their position by being partly or wholly imbedded in sand, mud, or some similar material. In such cases the resistance to be overcome by the explosion is greater than if, under conditions otherwise similar, the charges were simply in direct contact with the water, and hence the interval is increased which must elapse before the water can complete the circuit of electricity.

The results of some experiments made at Chatham appear to show that, under such circumstances, the number of charges ignited at one time by the magneto-electric apparatus must be greater than if they were simply immersed in water. One experiment has already been mentioned, in which thirteen charges out of twenty-five were exploded at one time, most of them being imbedded in mud.

On another occasion the charges were placed in small pits filled with water, the canisters being covered in with mud beneath the latter. Nine of the charges were fired; the branch wire of the tenth was accidentally severed at the moment of the explosion, from its lying across one of the pits.

An attempt was made to fire simultaneously fourteen charges similarly arranged, by the current obtained from a large lever-magnet, but only seven were exploded; the other seven were fired on a second trial. It should be mentioned that the length of extended wire and the interval between the earth-connections were greater in these experiments than in those made at Woolwich with the large magnet, in which twenty-five charges were fired with perfect certainty by the single current obtained from it. Possibly the very great difference in the results obtained might have been partly due to some minute defects in the insulation of the branch wires employed at Chatham, which escaped notice on the inspection of the wires, but sufficed to diminish the intensity of the current when these were immersed in water.

It is most difficult, even in a long-continued series of carefully-observed experiments, to separate the pure results furnished by the application of a system, from results which are brought about, or at any rate greatly modified, by accidental circumstances. It appears, however, apart from the latter, that in the application of electricity (whether frictional or magnetic) to the explosion of

charges the effects to be produced by the current are modified by the resistance offered to it in its passage along wires of very considerable length, and that the effects of the current seem very much less when the insulated wire is extended than when it is employed in the form of a coil.

The retardation in the explosion of several charges in divided circuit by a rapid succession of currents, and the diminution in the number of charges fired by one single powerful current, both of which results were repeatedly noticed in the course of the many experiments with the galvanic battery, and with the permanent magnet, could only be ascribed to modifications in the intensity of the electricity by the greater resistance which is encountered.

Robert Hare, Professor of Chemistry in the University of Pennsylvania, was the first who applied electricity to the explosion of mines. Hare found, if an electric current of sufficient force was established in a circuit (X Y Z, Fig. 1193) of copper wire by either a permanent magnet, or galvanic battery, that a short piece of iron wire (Q, Fig. 1193), much thinner than the copper wire, making part of the circuit (P R, 23, Fig. 1193), was burnt, and exploded gunpowder and other explosive substances through which the iron wire was made to pass. Hare's discovery may be practically applied by the following simple process:—Two copper wires, A B, C D, Fig. 1210, being procured, about $\frac{1}{16}$ in. in diameter and 10 ft. in length, well covered with silk or cotton tarred, so that their insulation may be good. These wires are twisted together for a length *a b* of 6 in., care being taken to leave their lower extremities, at B and D, free, for a length of about $\frac{3}{4}$ an in. (separating them about $\frac{1}{2}$ an in.); from the extremities B, D, the insulating envelope must be removed; and a fine iron wire is stretched between B and D. Metallic contact must be established between the iron and the copper. The upper extremities A, C, of the two copper wires are connected with a circuit. For example, if A, Fig. 1210, be connected with P, Fig. 1193, and C with R, the iron wire B D will be consumed as soon as a galvanic or electric current, sufficiently powerful, is established by inserting the contact-peg, M, Fig. 1193.

1210.

Explosive Compounds Employed in Blasting.—Nitro-Glycerine is a most powerful explosive agent, and although not extensively used in England, it has been most successfully employed on the Continent and in America. It was discovered by Ascagne Sobero, an Italian, in 1847, but its practical application to mining purposes is principally due to the researches of Alfred Nobel, a Swedish mining engineer.

Nitro-glycerine is made in the following manner:—Fuming nitric acid (sp. gr. about 1·52) is mixed with twice its weight of the strongest sulphuric acid, in a vessel kept cool by being surrounded with cold water. When this acid mixture is properly cooled, there is slowly poured into it rather more than one-sixth of its weight of syrupy glycerine; constant stirring is kept up during the addition of the glycerine, and the vessel containing the mixture is maintained at as low a temperature as possible by means of a surrounding of cold water, ice, or some freezing mixture. It is necessary to avoid any sensible heating of the mixture, otherwise the glycerine, which is the sweet principle of oil, would be, to a considerable extent, transformed into oxalic acid. When the action ceases, nitro-glycerine is produced. It forms on the surface as an oily-looking fluid, the undecomposed sulphuric acid forming the subjacent layer, owing to its greater specific gravity. The whole mixture is then poured, with constant stirring, into a large quantity of cold water, when the relative specific gravities become so altered that the nitro-glycerine subsides and the diluted acid rises to the surface. After the separation in this manner into two layers is effected, the upper layer may be removed by the process of decantation or by means of a siphon, and the remaining nitro-glycerine is washed and re-washed with fresh water till not a trace of acid reaction is indicated by blue litmus paper. The final purifying process, pursued by Nobel, is to crystallize the nitro-glycerine from its solution in wood naphtha. This final process is not necessary when the compound is to be used at once.

As prepared in this manner, nitro-glycerine is an oily-looking liquid, of a faint yellow colour, perfectly inodorous, and possessed of a sweet, aromatic, and somewhat piquant taste. It is poisonous, small doses of it producing headache, which may also be produced if the substance is absorbed into the blood through the skin, and hence it is not desirable to allow it to remain long in contact with the skin, but rather to wash it off as soon as possible with soap and water. Glycerine has a specific gravity of 1·25–1·26, but the nitro-glycerine has a specific gravity of almost 1·6, so that it is a heavy liquid. It is practically insoluble in water, but it readily dissolves in ether, in ordinary vinic alcohol, and in methylic alcohol or wood spirit. If it be simply exposed to contact with fire it does not explode, although it is so powerful as an explosive. A burning match may be introduced into it without producing any explosion; the match may be made to ignite the liquid, but combustion will cease as soon as the match ceases to burn. Nitro-glycerine may even be burned by means of a cotton wick or a strip of bibulous paper, as oil from a lamp, and as harmlessly. It remains fixed and perfectly unchanged at 212° Fahr.; if heated to about 360°, however, it explodes. It detonates when struck by the blow of a hammer, but only the part struck by the hammer explodes; the surrounding liquid remains unchanged.

As the carriage of nitro-glycerine is dangerous, many trials have been made to render it inexplosive, and to restore its explosiveness with equal readiness. Nobel's method of making it inexplosive is at once simple and effective. It is to mix with it from 5 to 10 per cent. of wood spirit, when all attempts at exploding it are rendered utterly futile. Five per cent. of methyl-alcohol is said to be amply sufficient to transform the nitro-glycerine into the inexplosive or pro-

tected state, but Nobel now always adds 10 per cent. before sending any of his blasting liquid into the market.

The transformation of protected into ordinary nitro-glycerine is effected by thoroughly agitating it with water, and allowing the mixture to settle for a short while. By this means the water dissolves out the methyl-alcohol, and the mixture of spirit and water readily rises to the surface, in virtue of its low specific gravity, and can be removed by means of a siphon, or by simply pouring it off. The blasting liquid is now ready for use. It would seem that the methyl-alcohol is by this means separated very readily from the nitro-glycerine held in solution by it. If protected blasting liquid be kept in a closed vessel, it will remain in that state for an indefinite period of time, and ready at any moment to be reduced or rendered fit for action; if, however, it be exposed in an open vessel, it will regain its explosiveness, in periods of time proportionate to the amount or degree of exposure.

The chief advantage which nitro-glycerine possesses is that it requires a much smaller hole or chamber than gunpowder does, the strength of the latter being scarcely one-tenth that of the former. Hence the miner's work, which, according to the hardness of the rock, represents from five to twenty times the price of gunpowder used, is so short, that the cost of blasting is often reduced to 50 per cent. The process is very easy. If the chamber of the mine present fissures, it must first be lined with clay to make it water-tight. This done, the nitro-glycerine is poured in and water after it, which, being the lighter liquid, remains at the top. A slow match, with a well-charged percussion cap at the end, is then introduced into the nitro-glycerine, or a fuze, to the extremity of which is attached a small quantity of gunpowder, fixed immediately over the liquid. The mine may then be sprung by lighting the match, there being no need of tamping. Experiments were made with this new compound in the open part of the tin mines of Altenburg, in Saxony. In one of these, a chamber, 34 millimètres in diameter, was made perpendicularly in a dolomitic rock, 60 ft. in length, and at a distance of 14 ft. from its extremity, which was nearly vertical. At a depth of 8 ft., a vault filled with clay was found, in consequence of which the bottom of the hole was tamped, leaving a depth of 7 ft. One litre and a half of nitro-glycerine was then poured in; it occupied 5 ft. A match and stopper were then applied as stated, and the mine sprung. The effect was so enormous as to produce a fissure 50 ft. in length, and another of 20 ft. The total effect has not yet been ascertained, because it will require several small blasts to break the blocks that have been partially detached by this.

Nitro-glycerine has, however, one disadvantage. It freezes at a temperature very probably above 92° Fahr., and it is said that even at a temperature of 43° to 46° Fahr. the oil solidifies to an icy mass, which mere friction will cause to explode. It is probable, however, that the freezing-point of the oil lies somewhat lower than is here stated, though as yet no exact determination of the freezing-point of the oil has been made. A newspaper from Hirschberg, in Silesia, gives a sad account of an accident, caused by the frozen oil exploding by friction. Nitro-glycerine was there being used in making a tunnel. It was kept in glass vessels, packed in straw, and placed in baskets, each vessel containing one-fourth to one-eighth of a hundredweight of the oil. For several days the oil had been frozen. It was carefully handled, and pieces were separated by means of a piece of wood, and put into the bore-holes, and it was found that the frozen nitro-glycerine exploded quite as well as the fluid. One day an overseer at the shaft hit upon the unlucky idea of breaking into pieces with a pick a 700 or 800 lb. lump of the frozen glycerine. The blow caused the mass to explode, and the unfortunate man was blown up into the air, and fell back into the shaft, some 40 or 50 ft. deep, whilst two workmen, who were making cartridges a short distance from him, luckily escaped with slight injuries.

Dynamite is made by mixing 75 per cent. of nitro-glycerine with 25 per cent. of powdered sand (silica). It has been introduced by A. Nobel, whose researches on nitro-glycerine are so well known. Dynamite retains all the properties of nitro-glycerine for blasting, but is not dangerous, as it may be handled freely, and does not explode by fire alone or when accidentally subjected to percussion. In some experiments made by the inventor, a box containing about 8 lbs. of dynamite (equal in power to 80 lbs. of powder) was placed over a fire, where it slowly burned away. Another box containing the same quantity was hurled from a height of more than 60 ft. on to a rock below, no explosion ensuing from the concussion sustained. Explosion is produced by means of a percussion cap in the same manner as with nitro-glycerine.

Schwartz's Blasting Gunpowder.—This powder is now much employed in mining. Its combustion is slow but complete. The following analyses show why it is cheaper than ordinary powder:—

	I.	II.
Soluble salts	74·55	74·32
Nitrate of potash	56·22	56·23
Nitrate of soda	18·30	18·09

The treatment by sulphide of carbon produced:—

Dissolved sulphur	9·68	7·61
Carbon remaining	14·14	15·01
Moisture	1·78	11

It is a coarse-grained powder, in which one part of potash nitre is replaced by nitrate of soda.

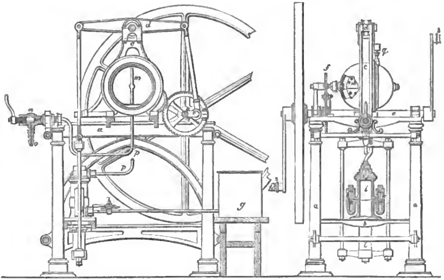
In the first instance, one part of nitrate of soda for one part of nitrate of potash was used, but it was afterwards found best to employ a third of nitrate of soda. See Artesian Wells. Battery. Gunpowder. Gun-Cotton. Ordnance. Quarrying. Telegraphy. Tunnelling.

BOTTLING MACHINE. Fr., *Machine à mettre en bouteilles*; Ger., *Pfropfmaschine*; Ital., *Macchina da toppar bottiglie.*

The bottling machine, shown in Figs. 1211, 1212, is chiefly used for soda and other aërated waters. It was invented by the late Hayward Tyler, and it is on the continuous principle. The

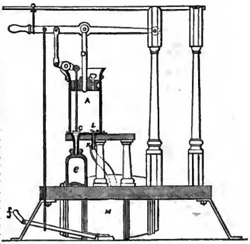
condenser and bottling-piece are shown in section Fig. 1211, to illustrate the internal construction. The same letters of reference refer to the same parts in Figs. 1211, 1212. Fig. 1211 is a side elevation, Fig. 1212 end elevation; one-half of the iron frame is taken away in Fig. 1211 to show

1211. 1212.



more clearly the working parts. The iron frame on which the whole of the working parts are fixed is removed for the same reason. *References:*—*b*, cast-iron stool for pump; *c*, carriage for condenser; *d*, wrought-iron beam, with connecting-rod to crank at one end, and side rods to the pump-piston frame at the other end; *e*, wrought-iron crank-shaft, with fly-wheel and two handles, *s*, *s*, which are used when hand-power is applied; *f*, brass wheel to work the agitator; *g*, copper solution pan; *h*, regulating cocks for gas and water, one only of which is shown; *i*, gun-metal pump, with separate valves for gas and water in the valve-pieces, which are marked *k k*. The delivery-valve is on the top of the pump; *l*, solid gun-metal piston working underneath the pump; *m*, agitator working inside the condenser to more intimately mix the gas and water together; *n*, bottling-piece fitted with a screw-valve and lever-handle; *o*, bottling nipple; *p p*, copper pipes, tinned inside, one to take the gas and water from the pump to the condenser, the other to convey them from the condenser to the bottling-piece; *q*, safety-valve to relieve the pressure in the condenser, in which there is also a pressure-gauge, not shown in the figures, to indicate the pressure suited to the different aërated waters. S, S, are handles for actuating the machine when worked by hand. The gas generator and gasometer, although not shown in Figs. 1211, 1212, are the same in all the machines employed for a similar purpose.

1213.



W. F. Davidson's bottling machine, Fig. 1213, is arranged so that the liquid to be bottled is

drawn from the barrel M through a suction-pipe K by a piston, a valve L being arranged so as to prevent the return of the liquid. The liquid is let into the bottle *e* from the pump-cylinder A through the valve C, which is operated by means of levers and rods. This valve is closed by means of a spring bar acting automatically. The plunger D is raised as soon as pressure is removed from the treadle *f*; thus giving an intermittent motion the work is continued.

BOTTOMING, OR BALLASTING. FR., *Empierrement;* GER., *Besteinung, Beschotterung;* ITAL., *Imbrecciare Inghiaiare.*

See PERMANENT WAY.

BOULDER-PAVING. FR., *Pavé en galet;* GER., *Rollsteinpflaster;* ITAL., *Ciottolato.*

See CONSTRUCTION.

BOULDER-WALLS. FR., *Mur en galet;* GER., *Rollstein Mauerwerk;* ITAL., *Muratura di ciottoli.*

See CONSTRUCTION.

BOUNDARIES. FR., *Limite;* GER., *Grenze;* ITAL., *Confine.*

In making a survey, the boundaries of the counties, parishes, and the several estates, are required to be marked correctly thereon; in ascertaining which, it is generally found necessary to procure the services of parties locally acquainted with the ground to be surveyed.

In the case of property divided by hedge and ditch, the brow of the ditch is generally the boundary; which, of course, forms the line to be measured. In some districts the roots of the quicks, or the foot of the bank, forms it: a width of 15 links is usually allowed for a hedge and ditch, 6 links for ditches between neighbouring estates, and 7 for those nearest roads, that is, from the roots of the quicks. See GEODESY. SURVEYING.

BOW-COMPASS. FR., *Compas à pompe;* GER., *Federzirkel;* ITAL., *Compassino da circoli.*

A pair of compasses for describing small circles with ink, is sometimes called a *bow-compass.* See COMPASSES.

BOW-PEN. FR., *Tire-ligne;* GER., *Reissfeder;* ITAL., *Penna a serbatoio.*

This pen is often termed a *drawing pen:* the part of it which holds the ink is formed of two cheeks which are bowed out towards the middle, and regulated by a screw. See COMPASSES.

BOW-DRILL. FR., *Archelet;* GER., *Drillbogen, Fidelbogen;* ITAL., *Trapano ad archetto.*

See HAND-TOOLS.

BOW-SAW. FR., *Scie à chantourner, scie en archet;* GER., *Schweifsäge;* ITAL., *Seghetto.*

See HAND-TOOLS.

BOX.

A cylindrical, hollow iron, used in wheels, in which the *axle* revolves, is called an axle-box.

A *box-drain* is a term generally applied to a small drain with vertical sides. See DRAINAGE.

BOXING OF A SHUTTER.

The part into which a shutter is folded when not required for use. It is formed by the inside lining of the sash-frame, the grounds of the architrave, and the *back lining.* See SASH-FRAME.

BOYAU. FR., *Boyau;* GER., *Gang des Laufgraben;* ITAL., *Ramo di trinciera;* SPAN., *Ramal.*

Boyaux, or boyaus, are small trenches, or branches of a trench, leading to a magazine, or to any particular point. See FORTIFICATION.

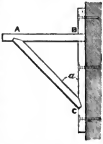
BRACE.

A brace is that part of a piece of framing which is subject to tension or compression, such as the diagonal bars of a Warren girder. It differs from a *strut,* which is subject to compression; or from a *tie,* which is subject to tension only. See BRIDGES.

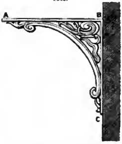
BRACKET. FR., *Palier, console, tasseau;* GER., *Unterlage, Lager, Consol;* ITAL., *Mensola, Beccatello.*

A bracket is an arm which projects from the face of a wall or post, chiefly used to sustain a shelf, roof, cornice, or other overhanging structure. It is usually supported at the outer end by a strut, as A C, Fig. 1214. The strain tending to pull the bearer A B out of its socket at B is represented by W tan. a; and that portion of the load which is transmitted to the wall along the strut A C is represented by $\frac{W}{\cos. a}$; W being the weight assumed to be concentrated at the point A, and a the angle which the strut makes with the wall. When the load is distributed over the bearer A B, the strains on it and on the strut A C will be reduced to one-half. The vertical strain or pressure on the wall or *upright* of the bracket will be equal to the load. A distributed load will cause a transverse strain on the bearer itself, in the same manner as a beam supported at both ends, or supported at one end and fixed at the other, as the case may be. In a solid bracket, or one of ornamental shape, as Fig. 1215, the strain at B is all that is usually required, and may be ascertained on the prin-

1214.



1215.



ciple of the lever. It will equal $\frac{W \times AB}{BC}$ for a load concentrated at A, and one-half that quantity when the load is distributed. See STRENGTH OF MATERIALS.

In large cornices, to save plaster it is usual to fix to the wall and ceiling, at intervals of 12 or 14 in., brackets cut roughly to the outline of the intended cornice; to these, laths are nailed, to take the plaster of the cornice. The brackets in the angles are called *angle-brackets*.

The term *bracket* is also applied to a projecting arm which carries on its end a gas-burner. Pieces of wood fixed on the end of the tread of stairs over the outer string-board are called brackets; they are sometimes made ornamental, in which case they are called *wrought* or *fancy brackets*; in other cases they are known as *cut brackets*. Brackets in stone are usually called *corbels*.

BRAKE, OR BREAK. FR., *Frein*; GER., *Bremse*; ITAL., *Freno*.

A piece of mechanism for retarding or stopping motion by friction, as of a carriage or railway, by the pressure of rubbers against the wheels. In Fig. 1216 the hand-wheel on the spindle A, which is fastened to the platform R of the car, winds up the chain F, and pulls the lever B, which presses the brake-block H upon the wheel G, and pulls the rod S, which presses the brake-block upon the wheel D, and pulls the rod E, which runs to the next truck, where there is a duplicate of the arrangement, shown in Fig. 1216. Thus, turning the brake-wheel at either end of the car brings an equal pressure upon all the wheels.

1216.

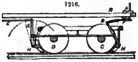
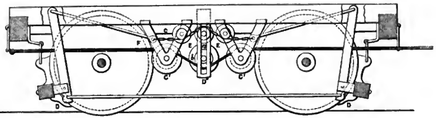


Fig. 1217 shows a railroad car brake, invented by A. J. Ambler; it belongs to that class of railroad brakes in which a tensional chain, or rods and chains, are used for operating or applying power from the locomotive to the brakes of a train of cars.

1217.



This arrangement of Ambler consists of fixed and sliding sheaves E, E, in connection with a tensional chain F, and brake-chain G; so that by operating the tensional chain F a movement will be imparted to the brake-chain G, to set or apply the brakes D, D. The slack of the tensional chain F will be taken up by the falling of the sliding sheaves E, E, when the power is removed from the chain F. The power of the brakes is limited and controlled by limiting the rising and falling movement of the *sheaves* E, E, by having the *axles* b of the sheaves fitted into slots a in the bars D″ D″. The sheaves C′, C′, are stationary.

The number of brake carriages or vans to a given train will depend on the inclinations on the line and the speeds employed: with passenger trains it has been considered that on an average, and to ensure safety, every fifth carriage should have a brake: the engine also is generally reversed to assist the brakes. It must be recollected, however, that by stopping a train too rapidly, great injury results both to the permanent way and the rolling stock. But still it is very important that those who have charge of a train should be able to stop it within a very short distance, when there is risk of collision, or any other danger is apprehended; and the greater the number of wheels to which brakes are applied, the more speedily will the effect be produced.

The following considerations appear to be those which would determine the amount of brake-power.

The forces which act on the train after the steam has been shut off are the axle friction and rolling friction of the train, and the pressure of the wind: the friction tends gradually to bring the train to rest,—the pressure of the wind to accelerate or retard it, as the case may be, and this will therefore be omitted from the conclusions to be drawn.

To stop a train rapidly, brakes are applied to some of the wheels, and the engine is reversed. The application of brakes prevents the wheels from revolving, and introduces the friction due to the weights on the wheels to which the brakes are applied. The act of reversing the engine does not immediately stop the forward motion of the driving-wheel, but forces it to revolve at a somewhat slower rate than that due to the speed of the train, and thus causes a friction of surfaces to take place between the wheel and rail.

The axle and rolling friction of the train may be assumed to be some proportion of the total weight of the train; the friction of the wheels to which brakes are applied may be taken as some proportion of the insistent weights; from experiments, it appears that the axle and rolling friction may be taken at $\frac{1}{250}$ part of the weight of the train, and the friction due to the brakes at about $\frac{1}{6}$ of the weights on them.

Hence, if l represent the gross load of the train,

w " the weights on the wheels to which brakes are applied,

R " the retardation in feet per second,

g " the force of gravity,

and, if the train be on an incline,

$\frac{1}{p}$ represent the slope of such incline,

$$R = \left(\frac{l-w}{334} + \frac{w}{8} \pm \frac{l}{p}\right)\frac{g}{l},$$

the latter term being used with the negative sign when the train is descending, and the positive sign when ascending, the gradient.

If S = space traversed by train in coming to rest,

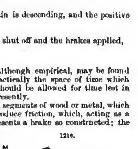
v = velocity in feet per second at the moment the steam is shut off and the brakes applied,

$$S = \frac{v^2}{2R}.$$

It should be observed that these estimates and formulas, although empirical, may be found useful in forming rough estimates; and that, in estimating practically the space of time which should be required for a train to stop in, one or two seconds should be allowed for time lost in applying the brakes. These combinations will be referred to presently.

Speaking in general terms, a brake consists of one or several segments of wood or metal, which can be pressed upon the circumference of a wheel, so as to produce friction, which, acting as a resistance, reduces the velocity of that wheel. Fig. 1218 represents a brake so constructed; the wooden blocks a, a, a, a, are connected by two straps of iron, movable round a fixed point O; the ends A and B of these two straps are fastened to the *bell-crank* A C B. As none of the centres of motion, A, B, C, are fixed, the arms A C, C B, have the power of a toggle-joint. If the handle M of the bell-crank is moved in the direction indicated by the arrow, the blocks are forced to press upon the rim of the wheel, and friction is thus produced, which diminishes the velocity of the wheel which is supposed to be in motion. In order to distribute the pressure over a large surface, so that the materials in contact be not altered, the brake should necessarily embrace a sufficient part of the circle. Cranes, and generally all machines for lifting and lowering weights by means of handles, are provided with a brake acting upon a special wheel which influences the movement of the chain barrel.

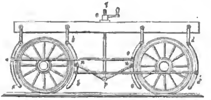
1218.



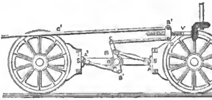
Also trains of great velocity are either stopped on inclines or their motion is retarded on railroads, as is well known, by applying a brake to the carriages. The brakes of common carriages are wooden blocks placed near the back wheels; by means of a handle and a screw, acting upon a system of levers, the blocks are pressed upon the rims of these wheels. These brakes are substituted with advantage for the ancient wooden shoe or sabot, which is still used by carters or wagoners; the use of that shoe is to prevent the wheel from turning, and it transforms the rolling friction into a sliding friction, which is much more considerable; it produces thus a resistance which tends to diminish the velocity of the carriage and to prevent its acceleration in descending inclines. But the use of the shoe is very incommodious, and serious accidents may happen if the chain, which holds the sabot or shoe, breaks. The brake acts in a more gradual manner, and its use is handier and safer.

In railway trains the brakes act simultaneously upon all wheels of the same carriage. Various constructions have been adopted for that purpose. Fig. 1219 shows one of the earliest, as used on the Versailles railway. The equal segments $a a'$, $b b'$, $c c'$, $d d'$, are placed at a little distance before and behind each wheel; they are suspended from the frame of the carriage by rods moving round fixed points. The levers $m p$ and $n p$, jointed to the middle of the arcs $b b'$ and $c c'$, are connected at p with a vertical rod $p q$, which has a screw at its end, and is raised or lowered by means of the nut e. The raising of the point p brings the points m and n nearer to the wheels, with the power of a toggle-joint, and the arcs $b b'$ and $c c'$ are pressed against the tires with great force; the same takes place with the arcs $a a'$ and $d d'$, which are connected with the arcs $b b'$ and $c c'$ by means of the coupling-rods $a c$ and $b' d'$; in this manner four arcs or blocks press upon the wheels at the same time. The blocks are either made of wood and hooped with iron, or they

1219.



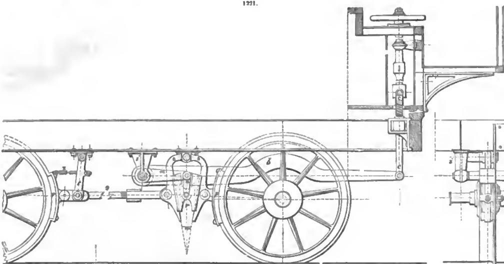
1220.



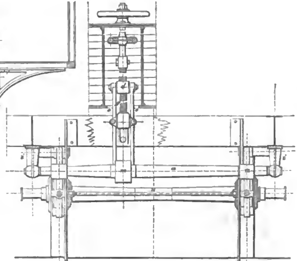
are made entirely of iron. Fig. 1220 represents a brake operated by compound levers: in general, this latter principle of construction is adopted.

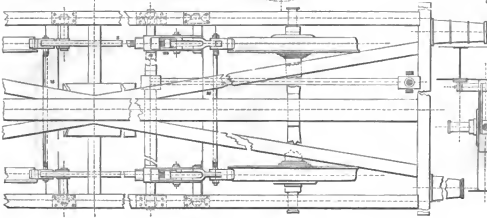
The two brake-blocks S and S', Fig. 1220, are connected with two equal levers A B and A' B,

1221.

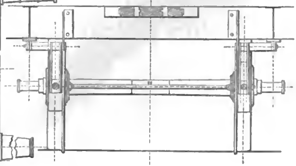


1223.





1222.



1224.

which are again fastened to a third lever B′BC, movable round a shaft O. The rod CD connects the end C of the lever B′BC with the nut DD′, which is moved backwards and forwards by the screw V; this screw, which can only move round its axis, but not in a longitudinal direction, is turned by wheel-gearing from the box of the guard or brakes-man. Therefore, by turning the brake-wheel to the right, the nut DD′ advances to the right and pulls the points C and B into the same direction, whilst the point B′ is pushed into the opposite direction, and the brake-blocks are consequently pressed upon the tires of the wheels. The coupling-rod C′D′, jointed at D′, produces an analogous effect upon the following wheels. The reverse takes place if the brake-wheel be turned in the opposite direction; that is, the blocks S, S′, are then removed from the wheels.

In order to bring the brake into full action a certain time is always required, and numerous constructions have been adopted for shortening this time as much as possible. One method is that of employing a weight of an oblong form with a rack and pinion on its longest vertical side: this weight moves between guides in a vertical direction, and is kept in its place by means of a click or spring. As soon as the guard removes the click or eases the spring, the weight falls, and turning the pinion rapidly round its horizontal axis, transfers the motion to the brake-blocks, which act in the manner previously described. By means of a handle the pinion is turned in the opposite direction, the weight is raised, and again fastened in its former position. It will be seen that the action of the brake under these circumstances must be very rapid, and a train can be stopped in a very short time.

But the advantages of this very great rapidity should not be exaggerated; a train should not be stopped instantaneously. To stop quickly is equal to a sudden shock against an obstacle, and might produce serious accidents. M. Gentil, mining engineer, has compared that shock with the one which the train would sustain by falling vertically from a certain height: the following Table gives the results of his researches:—

Trains.	Speed an hour, in kilomètres.	Speed a second, in mètres.	Height of Fall, in mètres.	Comparison.	Remarks.
	kilos.	m.	m.		
Goods train ..	25	6·94	2·456	Ground floor	The consequences of the shock of an express train suddenly stopped, would be the same as if that train had fallen from a fourth floor, or from a height of 46 ft.
Mixed	30	8·33	3·533	1st "	
Passenger ..	40	11·11	6·293	2nd "	
Mail	50	13·88	9·825	3rd "	
Express	60	16·66	14·159	4th "	

The law in France demands one brake-van to seven carriages or less; two brake-vans if the number of carriages varies between seven and fifteen; three brake-vans for a train of more than fifteen carriages; the tender-brakes are not included in that number.

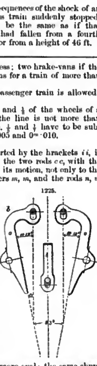
On the Turin-Genoa railway one brake-van to two carriages of a passenger train is allowed; and three wagons of a goods train to a brake-van.

In Prussia $\frac{1}{8}$ of the total number of wheels of a passenger train, and $\frac{1}{4}$ of the wheels of a goods train, have to be provided with brakes, if the inclination of the line is not more than $0^{m}·0033$ the mètre. For an inclination between $0^{m}·0033$ and $0^{m}·005$, $\frac{1}{6}$ and $\frac{1}{3}$ have to be substituted for these fractions, and $\frac{1}{4}$ and $\frac{1}{2}$ for an inclination between $0^{m}·005$ and $0^{m}·010$.

Figs. 1221 to 1224 represent the arrangement of Stilmant's brake.

It is apparent from these figures that the horizontal shaft *a*, supported by the brackets *i i*, is moved by means of a long lever *b*, which is connected at its end, by the two rods *c c*, with the nut *d*; this nut being raised or lowered by the spindle *g*, transfers thus its motion, not only to the lever *b* and the shaft *a*, but from there also by means of the forked levers *m*, *m*, and the rods *n*, *n*, to the wedges *r r*. These wedges are made of cast iron, and form two symmetrical parts, which are supported by means of a joint or hinge; four sliding parts *o*, *o*, two of which carry directly the brake-blocks *p*, *p*, whilst the two others are kept in their respective positions by means of the pressure-rods *s*, *s*, serving as guides to the wedges.

1225.



The greatest angle formed by these sliding parts and the wedges, during the inactivity of the brake, is 23 degrees; at the moment of putting the brake in action this angle becomes less, since the sliding parts are pressed more towards the outside; and at the greatest pressure of the wedges against the sliding parts the angle is about 19 degrees.

The thread of the brake-screw *g* ought to be double, so that the lever *b*, the end of which has to pass through a very considerable arc, can be moved as quickly as possible. The brake-blocks which are not directly fastened to the wedges are kept in their respective positions by means of the suspension-rods *t t*, and the horizontal rods *u u*. The spiral springs *z z* keep the brake-blocks during the inactivity of the brake at a sufficient distance from the tires, and thus prevent any unnecessary friction. The free action of the suspension-springs during the stopping of the wheels has now been obtained simply by bending the sliding parts *o*, *o*, which serve as guides for the wedges *r r*, to a certain angle, and by making the holes in these sliding parts more oval; the same shape is given to the hole at the lower part of the suspension-rods *t t*, that is to say, where those rods

are fastened to the coupling-rods *s s*, Fig. 1225. The chief centre lines of the holes in the sliding parts form with the side *a b* an angle of 10 or 12 degrees; the diameter of these holes is 41 millimètres, their length 61 millimètres, thus giving to the springs a play of 20 millimètres, sufficient for the oscillations during the running of the wagon.

A few words may be said here with respect to brake-blocks in general, and with respect to iron blocks in particular. Some time ago brake-blocks were made of soft wood, such as elm, beech, poplar, and so on, which is less susceptible to become polished by friction than iron; the rapid wear and tear, however, requiring often and expensive renewing of the blocks, have induced many engineers to substitute metal, and especially iron, in place of wood.

The use of self-acting brakes in engines of Engerth's system requires great care in descending inclines of 8 millimètres near Loxeville. The wooden brake-blocks of the tender catch fire very often, and are entirely destroyed when the train reaches the station. In order to prevent this inconvenience, iron blocks have been substituted for the wooden ones.

The following are the results of that application:—

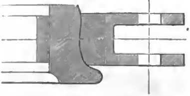
1. With wooden brake-blocks the wheels of the tender had to be stopped in order to prevent heating and the re-turning of the tires after a run of 9000 kilomètres. Since iron brake-blocks are adopted on some of the French railways, the wheels are allowed to turn slowly in descending inclines; several tenders have already run over 12,000 kilomètres without the tires of the wheels requiring to be cooled.

2. The wear and tear of the iron brake-blocks has been 14 or 15 millimètres for an average distance of 15,000 kilomètres.

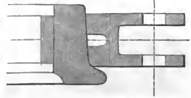
Those results have been fully confirmed by the experiments made with Stilmant's brake; and it has since been found that a better retardation of the motion of the train is obtained if the blocks are not pressed upon the wheels during the whole time required for the stopping of a train, but are lifted up and pressed upon again at very short intervals.

It has been, however, observed that the tires of the wheels, especially those of the tender, and the iron brake-blocks used at present, acquire very quickly, not only the shape shown in Fig. 1226, but often deep grooves are cut around the whole circumference of the tires. These grooves are produced either by grains of sand, which find their way between the tires and the brake-blocks, or by impurities of the iron. In order to prevent this disadvantage, M. Stilmant has proposed brake-blocks of cast steel, shown in transverse section, Fig. 1227. The surface of these blocks, which comes in contact with the tires of the wheels, is divided into two equal parts of 32 millimètres width; the central groove has a width of 20 millimètres and a depth of 36 millimètres, which gives sufficient room for a current of air to pass through.

1226.



1227.



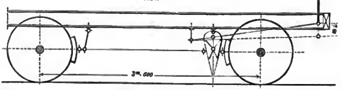
To find by Calculation the Pressure and Power of this Brake.—It will be seen from Fig. 1228 that the brake is composed of a combination of different simple machines, which can act each separately, and transfer the produced effect successively from one upon the other, and accumulate thus a very considerable pressure, which it would be impossible to obtain, under the same conditions, by one or the other of these simple machines alone.

The obtained pressure is very variable, and depends chiefly upon the power exercised by the guard upon the handle or wheel of the screw.

Referring to Fig. 1228, and putting

$R = 0^{m}\cdot 220$, the length of the handle or the radius of the brake-wheel;
$r = 0^{m}\cdot 023$, the radius of the brake-screw;
$h = 0^{m}\cdot 044$, the thread of the screw;
$f = 0\cdot 08$, the coefficient of friction of the screw; and
$P = 30^{k}$, the force of the guard on the handle or the wheel;

1228.



we get as the work of the screw the pressure $Q = \frac{P R}{r} \times \frac{2 \pi r - f h}{h + 2 \pi r f}$: the given values being sub-

stituted, we have $Q = \frac{30 \times 0\cdot22}{0\cdot023} \times \frac{2 \times 3\cdot14 \times 0\cdot023 - 0\cdot08 \times 0\cdot044}{0\cdot044 + 2 \times 3\cdot14 \times 0\cdot023 \times 0\cdot08} = 727^{k}\cdot89$, or about 728 kilogrammes.

The effective weight of the suspension-rods $c\,c = 16^{k}$ has to be added to this pressure, so that the total force at the end of the lever b is equal to $Q = P_1 = 728 + 16 = 744$ kilogrammes.

Calling, therefore,

$L = 2^{m}\cdot065$, the length of the lever b;
$p = 80^{k}$, its own weight reduced to the centre of gravity;
$L_1 = 0^{m}\cdot970$, distance of centre of gravity from the centre of the horizontal shaft;
$l = 0^{m}\cdot365$, length of the small levers;
$p_1 = 18^{k}$, weight of the lever reduced to its centre of gravity; and
$l_1 = 0^{m}\cdot200$, distance of centre of gravity from the centre of the horizontal shaft;

the pressure produced by the lever is equal to $Q_1 = \frac{P_1 L + p L_1 + p_1 l_1}{l}$; or substituting again the given values, $Q_1 = \frac{744 \times 2\cdot065 + 80 \times 0\cdot97 + 18 \times 0\cdot2}{0\cdot365} = 4431^{k}\cdot67$, or very nearly 4432 kilogrammes.

Adding again the effective weights of the suspension-rods $n\,n$, of the bolts for the joints of the wedges, &c., equal to 53 kilogrammes, we get the total pressure produced upon the wedges,

$$Q_1 = P_2 = 4432 + 53 = 4485 \text{ kilogrammes.}$$

Taking, finally, the angle formed by the two parts of the wedges at the moment the brake is applied, $\alpha = 19°$, therefore $\beta = 80°\ 30'$, and $f_1 = 0\cdot18$ the coefficient of friction of the wedges, we get altogether the considerable pressure of $Q_2 = \frac{\text{tang. } \beta + 2 f_1 + f_1^2 \text{ tang. } \beta}{2 (1 + f_1 \text{ tang. } \beta)} \times P_2$, or

$$Q_2 = \frac{\text{tang. } 80°\ 30' + 2 \times 0\cdot18 + 0\cdot18^2 \times \text{tang. } 80°\ 30'}{2 (1 + 0\cdot18 \times \text{tang. } 80°\ 30')} \cdot Q_2 = 2\cdot699 \times 4485 = 12105 \text{ kilogrammes,}$$

which gives a pressure upon each brake-block of $\frac{Q_2}{4} = \frac{12105}{4} = 3026$ kilogrammes.

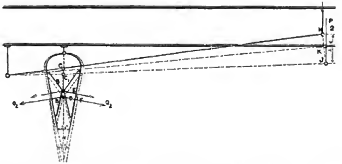
This pressure is considerably increased by the impulse given to the blocks from the wheels as they rotate; according to experiments made with the pressure or coupling rods $s\,s$, it can be taken as 4500 or 5000 kilogrammes. Now, if the coefficient of friction of the block be put equal to 0·4, the effort of this friction will be $T = 4500 \times 0\cdot4 = 1800$ kilogrammes, which is much greater than the adhesion of the wheels.

Time required for the Action of the Brake.—Although the stopping of wheels by means of screw-brakes is generally considered a slow operation, yet stopping a train by Stilmant's system is an exception, on account of the rapidity of its action, which is as prompt as in the best constructions, while at the same time it possesses many other advantages. Besides, the small space between the brake-blocks and the tires of the wheels very much facilitates the quick and effective action of Stilmant's brake.

Supposing now that in a well-constructed brake the distance between blocks and tires is equal to $0^{m}\cdot003$, and taking the play between the axle-boxes and the plates in which they move to equal $0^{m}\cdot003$, we find:—That the friction between the blocks and the tires of the wheels only commences when the blocks will have passed through a distance of $0^{m}\cdot003$ (a); and that the braking of the wheels takes place immediately after a distance of $0^{m}\cdot006$ (which may be less) is passed (b).

It is thus necessary to determine the distance $B\,B_1 = C\,C_1$, Fig. 1229, which the wedges have to travel before the blocks touch the wheels.

1229.



For this purpose we find in the triangle E D F, at first, that $E = \frac{a}{2} = 11°\ 30'$, and $D\,F = 0^{m}\cdot003$; next, that $E = \frac{a}{2} = 9°\ 30'$, and $D\,F = 0^{m}\cdot003$; and consequently (a) for the contact between blocks and tires; $E\,F = B\,B_1 = D\,F$ cotang. E, or $B\,B_1 = 0\cdot003$ cotang. $11°\ 30' = 0^{m}\cdot01472$,

whence the distance travelled by the end of the long lever b, $\mathrm{H\,K} = \dfrac{0\cdot014 \times 2\cdot065}{0\cdot365} = 0^{\mathrm{m}}\cdot0834$, or the number of revolutions of the handle of wheel, if the thread of the screw is equal $0^{\mathrm{m}}\cdot044$, $n = \dfrac{0\cdot0834}{0\cdot044} = 1\cdot9$ revolutions. For the stopping of the wheels (b), $\mathrm{E\,F} = \mathrm{B\,B_1} = \mathrm{D\,F}$ cotang. E, $\mathrm{B\,B_1} = 0\cdot003$ cotang. $9°\ 30' = 0^{\mathrm{m}}\cdot01793$, whence the distance travelled by the lever,

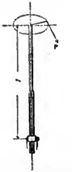
$$\mathrm{K\,J} = \frac{0\cdot01793 \times 2\cdot065}{0\cdot365} = 0^{\mathrm{m}}\cdot1014,$$

and the number of revolutions of the handle or brake-wheel $n = \dfrac{0\cdot1014}{0\cdot044} = 2\cdot3$. Thus the total distance through which the end of the lever b has to move will be $\mathrm{H\,J} = 0\cdot0834 + 0\cdot1014 = 0^{\mathrm{m}}\cdot1848$, or $n = \dfrac{0\cdot1848}{0\cdot044} = 4\cdot2$ revolutions, requiring about 10 or 12 seconds. An express train, running 60 kilomètres an hour, or $16^{\mathrm{m}}\cdot66$ a second, can therefore be stopped by means of two of Stilmant's brakes upon a length of less than 500 mètres; this result has been corroborated by experiments.

Construction of, and Work done by, the Principal Parts of the Brake.—Amongst the many parts which compose the mechanism of the brake, there is a certain number, the dimensions of which ought to be carefully calculated. These parts are:—The shank of the screw (a): the rods transmitting the pressure of the screw to the lever (b): the main lever (c); the two small levers (d); the brake-shaft (e); and the coupling or pressure rods (f).

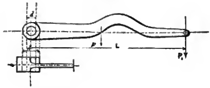
Screw of the Stem or Shank of the Brake (a).—Suppose the minimum diameter of the stem of the screw, Fig. 1230, be $0^{\mathrm{m}}\cdot035$, and taking the same values given above, we get $\mathrm{P}\,r = \dfrac{\mathrm{R_1\,J}}{n}$, or substituting for $\dfrac{\mathrm{J}}{n}$ its value $= \dfrac{\pi\,d^3}{16}$, $\mathrm{P}\,r = \dfrac{\mathrm{R_1}\,\pi\,d^3}{16}$, whence $\mathrm{R_1} = \dfrac{16\,\mathrm{P}\,r}{\pi\,d^3}$; or introducing the values, $\mathrm{R_1} = \dfrac{16 \times 30 \times 0\cdot22}{3\cdot14 \times 0\cdot035^3} = 784400$ kilogrammes, or about $0^{\mathrm{k}}\cdot800$ to the square millimètre. Taking the modulus of elasticity for the torsion, $\mathrm{G} = 6600000000$ kilogrammes, we find the angle of torsion, $t = \dfrac{\mathrm{P}\,r\,\mathrm{L}}{\mathrm{J\,G}}$; or substituting again for J its value $= \dfrac{\pi\,d^4}{32}\,0\cdot098\,d^4$, $t = \dfrac{\mathrm{P}\,r\,\mathrm{L}}{0\cdot098\,d^4\,\mathrm{G}}$, or $t = \dfrac{30 \times 0\cdot22 \times 1\cdot5}{0\cdot098 \times 0\cdot035^4 \times 6600000000} = 0°\cdot0102$, that is to say, $0°\ 0'\ 36''7$.

1230.



1231.

1232.



Rods Transmitting the Pressure to the Lever (b), Fig. 1231.—The pressure which has to be transmitted, as has been shown previously, is equal to 744 kilogrammes; therefore for each pair of rods (there being always two) $\dfrac{744}{2} = 372$ kilogrammes. We thus obtain $\mathrm{P\,L^2} = \pi^2\,\mathrm{J\,E}$; or substituting for J its value $= \dfrac{b^3\,h}{12}$, $\mathrm{P\,L^2} = \dfrac{\pi^2\,b^3\,h\,\mathrm{E}}{12}$, whence $\mathrm{E} = \dfrac{12\,\mathrm{P\,L^2}}{\pi^2\,b^3\,h}$.

When the corresponding values are introduced, we have

$$\mathrm{E} = \frac{12 \times 372 \times 0\cdot9^2}{3\cdot14^2 \times 0\cdot02^3 \times 0\cdot045} = 1018546500 \text{ kilogrammes.}$$

Now, $\mathrm{E} = \dfrac{\mathrm{P\,L}}{\mathrm{A\,E}}$, whence $i = \dfrac{\mathrm{P\,L}}{\mathrm{A\,E}}$; or substituting the values,

$$i = \frac{372 \times 0\cdot9}{0\cdot0009 \times 1018546500} = 0^{\mathrm{m}}\cdot000365.$$

i is the shortening and A the area of the transverse section of the rod.

The Main Lever (c), Fig. 1232.—The force acting at the end of the lever is again, as in the case above, $\mathrm{P} = 744$ kilogrammes, besides the weight p of the lever, which acts at its centre of gravity.

The equation for equilibrium will be $(\mathrm{P} + \frac{1}{2} p)\,\mathrm{L} = \frac{\mathrm{R\,J}}{n}$; or substituting for $\frac{\mathrm{J}}{n}$ its value, we obtain, for the section taken in the central axis, $(\mathrm{P} + \frac{1}{2} p)\,\mathrm{L} = \frac{\mathrm{R}\,b\,(h^3 - h_1^3)}{6\,h}$, whence

$$\mathrm{R} = \frac{6\,h\,(\mathrm{P} + \frac{1}{2} p)\,\mathrm{L}}{b\,(h^3 - h_1^3)}, \text{ or } \mathrm{R} = \frac{6 \times 0{\cdot}17 \times (744 + 40) \times 2{\cdot}065}{0{\cdot}13 \times (0{\cdot}17^3 - 0{\cdot}09^3)} = 3036100 \text{ kilogrammes,}$$

say about 3 kilogrammes to a square millimètre; for the section taken before the centre, $(\mathrm{P} + \frac{1}{2} p)\,\mathrm{L} = \frac{\mathrm{R}\,b\,h^2}{6}$, whence $\mathrm{R} = \frac{6\,\mathrm{L}\,(\mathrm{P} + \frac{1}{2} p)}{b\,h^2}$, or $\mathrm{R} = \frac{6 \times 1{\cdot}98\,(744 + 40)}{0{\cdot}04 \times 0{\cdot}17^2} = 8057024$ kilogrammes, that is to say, about 8 kilogrammes per square millimètre.

The flexure of the lever is obtained by the formula $f = \frac{4\,(\mathrm{P} + \frac{1}{2} p)\,\mathrm{L}^3}{\mathrm{E}\,b\,h^3}$, or

$$f = \frac{4 \times 784 \times 2{\cdot}065^3}{20000000000 \times 0{\cdot}04 \times 0{\cdot}17^3} = 0^{\mathrm{m}}{\cdot}007; \text{ say, 7 millimètres.}$$

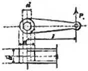
The Small Levers (*d*), Fig. 1233.—There are also two of these levers, and they are formed like a fork. The strain upon each of them will be

$$\left[\frac{(\mathrm{P} + \frac{1}{2} p)\,\mathrm{L}}{2\,l}\right] - \frac{1}{2}\,p_1 = \left[\frac{(744 + 40) \times 2{\cdot}065}{2 \times 0{\cdot}365}\right] - \frac{9}{2} = 2213 \text{ kilogrammes;}$$

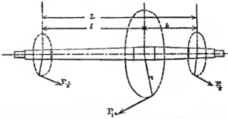
and the equation for equilibrium is thus again $(\mathrm{P} + \frac{1}{2} p)\,l = \frac{\mathrm{R\,J}}{n}$; or substituting for $\frac{\mathrm{J}}{n}$ its corresponding value, we get, for the section at the centre, $(\mathrm{P} + \frac{1}{2} p_1)\,l = \frac{\mathrm{R}\,b\,(h^3 - h_1^3)}{6\,h}$, whence $\mathrm{R} = \frac{(\mathrm{P} + \frac{1}{2} p_1)\,6\,h\,l}{b\,(h^3 - h_1^3)}$, or $\mathrm{R} = \frac{(2213 + 4{\cdot}5) \times 6 \times 0{\cdot}135 \times 0{\cdot}365}{0{\cdot}13\,(0{\cdot}135^3 - 0{\cdot}085^3)} = 2633000$ kilogrammes, that is to say, $2^{\mathrm{k}}{\cdot}633$ to the square millimètre; for the section before the centre, $(\mathrm{P} + \frac{1}{2} p)\,l = \frac{\mathrm{R}\,b\,h^2}{6}$, whence $\mathrm{R} = \frac{(\mathrm{P} + \frac{1}{2} p_1) \times 6\,l}{b\,h^2}$, or $\mathrm{R} = \frac{(2213 + 4{\cdot}5) \times 6 \times 0{\cdot}298}{0{\cdot}03 \times 0{\cdot}13^2} = 7824240$ kilogrammes, or about 8 kilogrammes per square millimètre.

The flexure of these levers will be $f = \frac{(2213 + 4{\cdot}5) \times 4 \times 0{\cdot}365^3}{20000000000 \times 0{\cdot}03 \times 0{\cdot}135^3} = 0^{\mathrm{m}}{\cdot}0003$.

1233.



1234.



Brake-Shaft (*c*), Fig. 1234.—The brake-shaft is submitted to two different strains, the one acting by flexure and the other by torsion. The first one is insignificant, and we shall only consider the other.

The moment of torsion for the part l_1 is $\mathrm{M} = (\mathrm{P} + \frac{1}{2} p)\,r\,\frac{l}{\mathrm{L}}$, which has to be kept in equilibrium by the moment of resistance, $\mathrm{M} = \frac{\mathrm{R}_1\,\mathrm{J}}{n} = \frac{\mathrm{R}_1\,\pi\,d^3}{16}$. We get, therefore, $(\mathrm{P} + \frac{1}{2} p)\,r\,\frac{l}{\mathrm{L}} = \frac{\mathrm{R}_1\,\pi\,d^3}{16}$, whence $\mathrm{R}_1 = \frac{(\mathrm{P} + \frac{1}{2} p)\,16\,r\,l}{\pi\,d^3\,\mathrm{L}}$, or $\mathrm{R}_1 = \frac{(744 + 40) \times 16 \times 2{\cdot}065 \times 0{\cdot}99}{3{\cdot}14 \times 0{\cdot}085^3 \times 1{\cdot}5} = 8873470$ kilogrammes, or very nearly 9 kilogrammes to the square millimètre.

For the part l of the shaft, the moment of torsion is $\mathrm{M} = (\mathrm{P} + \frac{1}{2} p)\,r\,\frac{l_1}{\mathrm{L}}$, therefore, as above, $(\mathrm{P} + \frac{1}{2} p)\,r\,\frac{l_1}{\mathrm{L}} = \frac{\mathrm{R}_1\,\pi\,d^3}{16}$, whence $\mathrm{R}_1 = \frac{(\mathrm{P} + \frac{1}{2} p)\,16\,r\,l_1}{\pi\,d^3\,\mathrm{L}}$, or

$$\mathrm{R}_1 = \frac{(744 + 40) \times 16 \times 2{\cdot}065 \times 0{\cdot}51}{3{\cdot}14 \times 0{\cdot}085^3 \times 1{\cdot}5} = 4571180 \text{ kilogrammes,}$$

say $4^{\mathrm{k}}{\cdot}5$ per square millimètre.

Finally, taking $\mathrm{G} = 6600000000$ kilogrammes, we find for the angle of torsion, $t = \frac{(\mathrm{P} + \frac{1}{2} p)\,r\,l\,l_1}{\mathrm{J\,G\,L}} = \frac{(\mathrm{P} + \frac{1}{2} p)\,r\,l\,l_1}{0{\cdot}098\,d^4\,\mathrm{G\,L}}$, or $t = \frac{(744 + 40) \times 2{\cdot}065 \times 0{\cdot}99 \times 0{\cdot}51}{0{\cdot}098 \times 0{\cdot}085^4 \times 6600000000 \times 1{\cdot}5} = 0^\circ{\cdot}01614$, or about $t = 0^\circ\,0'\,58''$.

Coupling or Pressure Rods (*f*). Fig. 1235.—The pressure upon each brake-block has been previously ascertained to be 4500 kilogrammes.

1235.

The equation of the equilibrium of these rods is $P L^2 = \pi^2 J E$; or substituting for J its value $= \frac{\pi}{64} d^4 = 0 \cdot 0491$, we find $P L^2 = \pi^2 \, 0 \cdot 0491 \, d^2$ E, whence $E = \frac{P L^2}{\pi^2 \, 0 \cdot 0491 \, d^4}$, or

$$E = \frac{4500 \times 2 \cdot 030}{3 \cdot 14^2 \times 0 \cdot 0491 \times 0 \cdot 055^4} = 2100000000 \text{ kilogrammes.}$$

$$\text{Now, } i = \frac{P L}{A E} = \frac{P L}{r^2 \pi E}, \text{ or } = \frac{4500 \times 2 \cdot 030}{0 \cdot 0275^2 \times 3 \cdot 14 \times 2100000000} = 0^{m} \cdot 0019.$$

In conclusion, we give diagrams representing some of the different types of brake frequently used.

Fig. 1236 shows the arrangement of a brake applied to tenders on the Western Railway of France. This brake shows at the same time with what facility eight brake-blocks may be adopted instead of two.

1236.

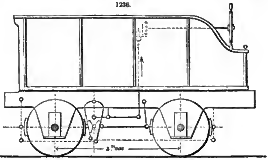


Fig. 1237 shows the brake for the goods wagons on the Eastern Railway of France.

1237.

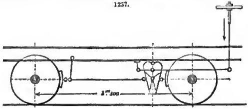
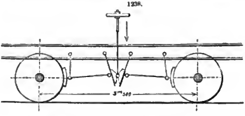


Fig. 1238, brake as adopted on the Northern Railway. A screw with a thread of only 12 millimètres transfers the pressure directly to the wedges.

1238.



1239.

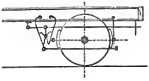


Fig. 1239 shows a hand-brake, acting either upon one wheel only, or upon the two wheels at the same time.

The weights of the brakes of these different systems are :—

1. For the brake of the tender, Fig. 1236, with eight brake-blocks, about 800 or 950 kilogrammes, of which 200 kilogrammes are of cast iron.

2. For the same brake with four blocks only, between 700 and 800 kilogrammes, of which about 150 kilogrammes are of cast iron.

3. For the brake of the goods wagons, as shown in Fig. 1237, between 600 and 650 kilogrammes, of which about 90 kilogrammes are of cast iron, and

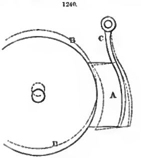
4. For the hand-brake, Fig. 1239, between 240 and 260 kilogrammes, of which 60 kilogrammes are of cast iron.

Numerous brakes have been invented for stopping railway carriages, but nearly all of them act upon the same general principle, and are simply different methods of pressing blocks of wood against the circumference of the wheel, so as to stop its revolution, and cause the tire to slide upon the rails.

If the wheels are all stopped, the friction of the weight of the carriage sliding upon the rails is the whole amount of braking power that can be obtained by any of the plans; and the different methods used to accomplish this add no power for stopping the carriages, but are only different ways of pressing the brake-blocks against the tires, for the purpose of ensuring greater rapidity, certainty, and uniformity of action, reducing the expenses of repairs, and the jarring on the carriage—or to make the brakes self-acting, or worked in combination.

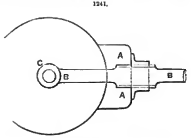
The principal object to be obtained is to have the blocks always pressed square against the wheels, and with a uniform pressure on all the wheels of the same carriage or wagon; unless this is effected there is great difficulty in stopping the wheels, and much straining is caused upon the carriage. In the earlier brakes the block is suspended by a vertical lever from the frame of the carriage or wagon, as shown in Fig. 1240, the block A being shaped to the circle of the wheel; but the varying height of the frame of the carriage, from the variation in the weight of load acting on the springs, causes much inequality in the fitting of the brake-block to the wheel, from the relative level of the brake-block and the wheel being changed, as shown by the dotted line B B; also, the action of the springs is stopped by the pressure of the brake, causing violent jarring and concussions, injurious both to the carriage and the road, and being very annoying to passengers.

1240.



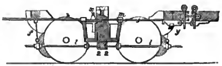
Hanging Brake.

1241.



Sliding Brake.

1242.



The slide-brakes, like those shown in Figs. 1241, 1242, were invented for the purpose of remedying these defects. The relative level of the wheel and the brake-block is preserved unchanged, by the brake-block A sliding horizontally upon a bar B B, which is carried by the axle-boxes at each end, C; a difficulty is experienced, however, in preserving an equal pressure on all the brake-blocks, on account of the unequal wearing of the different bearings.

Davis' brake, Fig. 1242, consists in the arrangement of a series of levers, rods, and springs, which are made to operate upon the brakes; so that when the locomotive ceases to propel the train the brake is applied to the wheels, and released when the locomotive is started. The sliding action is effected by the use of rods j, k, l, m, which are thrown into or out of action by the catch y. The reciprocating motion is maintained by compound levers acted upon at x, and springs placed at z z.

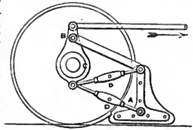
All the above brakes have, however, the serious objection that flat places are worn upon the tires of the wheels, by sliding upon the rails; and the wheels consequently become, to a certain degree, polygonal. Any deviation from the circular form of the wheel becomes a serious source of injury both to the rails and the wheel, from the amount of concussions caused by the great velocity of rolling, and the great weight carried; this also causes increased expense in the wear of the tires and rails.

In Lee's brake, Fig. 1243, the wooden brake-block A is made of a triangular form, and is pressed both against the wheel and the rail by the lever B, which is centred upon the nave of the wheel C, by means of a ring or collar fitting in a circular groove cut round the nave; the rubbing

face of the wood block is shod with copper or iron. The connecting-rods D D have adjusting-screws, to preserve the relative position of the brake-block A and the wheel, as the surface of the block wears away.

The mechanical arrangement of this brake, it will be perceived, does not admit of sufficient pressure being applied against the wheel and the rail to form an efficient brake; but even if the pressure were sufficient to stop the wheel, the same objection would still apply as in the ordinary brake, namely, flat places would be worn on the wheel. This brake was tried on one or two railways, but has not come into use.

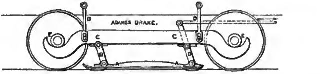
1243.



Lee's Brake.

Adams's brake, Fig. 1244, consists of a sledge A A sliding upon the rails, upon which the whole weight of the carriage is thrown by lifting the wheels off the rails. The sledge A A is a long piece of iron, with a flange at each end to guide it on the rails, and is suspended by two links B B from the iron bar C C, which is supported by the links D D, and bears against the under-side of the axle-box at each end, E E; the links B B are in the form of a parallel rule, and when they are straightened by the action of the lever, the sledge A A is pressed upon the rails, and lifts up the wheels from their bearing on them. This brake saves the wheels from

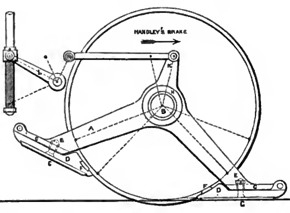
1244.



being worn flat; but it requires great power to put the whole weight of the carriage upon the sledge, and is consequently slow in action; and there is also an objection to it in having the wheels hanging without any support when the brake is in action. It has not come into use in England, but several brakes on this principle have been used in Belgium for some time previously.

Handley's brake, Fig. 1245. This brake is on the same principle as the ordinary skid used on common roads; the two iron arms A A are carried by the axle B, upon which a brass ring H is fitted,

1245.



turning round the axle; and at the end of these arms are fixed the shoes or skids C C, one of which is made to pass under the wheel, whichever way the carriage is running, raising it from the rails by turning the lever round upon the axle. The shoe is made the breadth of the tread of the wheel, without any flange, and the wheel is lifted only about $\frac{1}{4}$ of an in. on the average, so that the flange

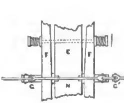
of the wheel continues as efficient and secure a guide upon the rails as in the ordinary case of a wheel stopped from revolving by the pressure of a brake-block. The shoe is made in two pieces: the upper one, C, is forged on to the arm A, and the lower piece, D, which forms the skid, is hinged to it at the end. The object of this construction is to prevent the shoe from touching the wheel until it is required to be put in action; the joint opens about $\frac{1}{2}$ of an in., and the shoe falls away from the wheel when it is lifted, being stopped by the bolt E, which limits the extent of its opening: and round this bolt is placed a short spiral spring, to keep the joint open, and prevent it from shaking when the carriage is running.

The wear of the shoe is provided for by inserting two small dove-tailed pieces, F end G, at the points where the wear takes place; these pieces are slightly tapered, and are driven into their places from the inner side, being burred or riveted on the opposite side, where they remain firmly fixed, having no tendency to work loose. The lower piece is of wrought iron, which is found to answer best for the purpose; the upper one, F, which carries the wheel, is of cast iron. It has very little wear upon it, but is changed occasionally for a piece of greater thickness, to allow for the wear of the shoe-plate G, and preserve the total thickness of the shoe, within a very little variation, so as to prevent much difference in the height that the wheel is lifted from the rails.

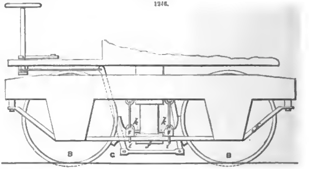
This brake is easily and quickly applied, by means of the lever L acting on the upper arm of the brake K, as the carriage runs upon the shoe when it is pressed under the wheel. The ordinary brake-screw, lever, and cross-shaft, are available for working this brake.

The brake, Figs. 1246, 1247, invented by D. Goodnow, of Albany, U.S., is very ingeniously arranged. The object the inventor had in view was to obviate those accidents that arise from applying the brakes of a railroad car to the outer sides of the four wheels of the truck, by a compact arrangement of the brakes in the centre between the wheels of the trucks, thereby exposing them to less danger of breaking, or their parts becoming detached. This arrangement further consists in so constructing the brake-bars, in combination with the jaw-braces of the trucks, that in case the bars are broken they cannot fall to the track and obstruct the wheels; further, in operating the two brakes conjointly by the direct endwise thrust of a short connecting-bar, both brake-blocks are made to act upon the wheels simultaneously.

1247.



1246.



The brake-bars F, F, Fig. 1246, extend beyond the jaw-braces *f*, *f*, to which they are connected by the yolks *i*, *i*. In Fig. 1247, E represents the position of the plank or *hang-frame* in relation to the brake-bars F, F, and the guide and safety rods *k*, *k*. How the brake-bars F, F, lever G, G', connecting-bar N, car-bearing E, and truck wheels B, B, are combined and arranged, is clearly shown in Figs. 1246, 1247.

Now we propose to place the subject of this article in a clear light, and in a plain practical form; since it has been handled in an erroneous, an obscure, or a slovenly manner, by most mechanical writers and experimentalists.

A carriage on a level railroad only requires a pressure of about $\frac{1}{300}$ part of the moving weight to give it motion, or from 4 to 8 lbs. a ton. The fraction $\frac{1}{300}$ is called the coefficient of friction; as these coefficients become smaller, the rubbing surfaces become smoother. All constant resistances may be expressed in a similar manner.

The work of every machine is consumed by the work done, or by the useful work, together with the useless work, or the work destroyed by the friction of the parts of the machine. We will here explain one of the most beautiful laws of motion: When the work applied exceeds the work consumed, the redundant work goes to increase the speed of the parts of the machine, and at the same time, like the fly-wheel, acts as a reservoir of work. *This acceleration goes on increasing until the work of the resistances + the useful work = the work applied; and then the motion of the machine becomes uniform.*

For example, in a railroad engine and train, at first the work of the engine exceeds the work of the resistances, and hence the speed of the engine goes on increasing; but, as the speed increases, the work of the resistances also increases, so that ultimately the engine attains a nearly uniform motion, which is called the greatest or maximum speed, and then the work destroyed by the resistances will be exactly equal to the work applied by the moving power. A few simple examples will make this law clear.

Ques.—Required the effective horse-power of a locomotive engine which moves at a steady speed of 23 miles an hour upon a level rail, the weight of the train being 100 tons, and the constant resistances amounting to 5 lbs. a ton?

Put x = the required horse-power.

The work of the engine a minute $= x \times 33000$ units of work.

The resistance $= 5 \times 100 = 500$ lbs.

The distance moved a minute $= \frac{23 \times 5280}{60} = 2024$ ft.; or $33\frac{11}{15}$ ft. a second.

Work to overcome the constant resistances, in a minute $= 2024 \times 500 = 1012000$ units of work.

But as the speed of the train is uniform, the work of the resistances will be equal to the effective work of the engine:

$$\therefore \quad x \times 33000 = 1012000 \qquad \therefore \quad x = \frac{1012000}{33000} = 30 \cdot 7 \text{ horse-power.}$$

Now suppose the uniform resistances and the power of the locomotive to be removed, then the train would move for a short time with a velocity (v) of $33\frac{11}{15}$ ft. a second, but would come to rest after passing over a space (s) of $7900 \cdot 888$ ft., when opposed by the constant resistance (f) of 500 lbs. on the level rails.

If the constant resistance (f) be 1000 lbs., this train would come to rest when $s = 3950 \cdot 444$ ft. When $f = 2000$ lbs., then $s = 1975 \cdot 222$ ft., and so on. The units of work conserved in a body weighing W lbs., moving with a velocity of v ft. a second, is equal to $\frac{W}{g} \times \frac{v^2}{2}$. See Byrne's 'Essential Elements of Practical Mechanics,' p. 97. In this case $g = 32 \cdot 2$ lbs., the supposed weight of a unit of mass. $\frac{W}{g}$ is termed the mass of a body whose weight is W lbs.

$$\text{Whence } \frac{W}{g} \times \frac{v^2}{2} = \frac{100 \text{ tons} \times 2240}{32 \cdot 2} \times \frac{(33\frac{11}{15})^2}{2} = 3950444 \text{ units of work;}$$

$$\text{and } f s = \ 500 \times 7900 \cdot 888 = 3950444,$$
$$\text{or } f s = 1000 \times 3950 \cdot 444 = 3950444,$$
$$\text{or } f s = 2000 \times 1975 \cdot 222 = 3950444, \text{ and so on.}$$

Ques.—What is the rate in miles an hour of a train of 80 tons, drawn by an engine of 70 horse-power, when the constant resistances amount to 8 lbs. a ton?

Call x the uniform speed in miles an hour.

Work used in moving the train x miles $= 80 \times 8 \times 5280 \times x$; this is the work done by the engine in an hour. But the work done by the engine in an hour will also be expressed by

$$33000 \times 70 \times 60;$$

$$\therefore \quad 33000 \times 70 \times 60 = 80 \times 8 \times 5280 \times x; \quad \therefore \quad x = \frac{33000 \times 70 \times 60}{80 \times 8 \times 5280} = 48 \cdot 02 \text{ miles.}$$

When the propelling power ceases to act, and a constant resistance of 11200 lbs. (f) (five tons) is applied, then this train will come to rest after passing over a space (s) of 894 ft. Since the uniform velocity (v) in this case is 60 ft. a second,

$$\therefore \quad \frac{W}{g} \times \frac{v^2}{2} = \frac{80 \times 2240}{32 \cdot 2} \times \frac{(60)^2}{2} = 10017392 \text{ units of work;}$$

$$\text{but, } f \times s = 11200 \times 894 = 10012800 \text{ units of work.}$$

Ques.—An engine of 48 horse-power moves with a maximum speed of 33 miles an hour on a level rail; required the gross load of the train, when the constant resistances amount to 6 lbs. a ton?

Let x be the gross weight of the train in tons; then the work consumed an hour in moving the train $= x \times 6 \times 33 \times 5280$.

Work of the engine an hour $= 48 \times 33000 \times 60$.

When the speed is uniform or at its maximum, $x \times 6 \times 33 \times 5280 = 48 \times 33000 \times 60$;

$$\therefore \quad x = \frac{48 \times 33000 \times 60}{6 \times 33 \times 5280} = 90\frac{10}{11} \text{ tons.}$$

In this example $f s = 7407307$ units of work $= \frac{W}{g} \times \frac{v^2}{2} = \frac{1000}{11} \times \frac{2240}{32 \cdot 2} \times \frac{(48 \cdot 4)^2}{2}$. Hence a constant resistance (f) of 3000 lbs. will bring this train to rest after it has passed over a space (s) of $2469 \cdot 102$ ft., for $f s = 3000 \times 2469 \cdot 102 = 7407307$ units of work.

Ques.—In what time will an engine of 66 horse-power, moving a train of 200 tons, complete a journey of 100 miles, friction and other constant resistances amounting to 5 lbs. a ton, rails horizontal?

Work expended in moving the train 100 miles $= 100 \times 5280 \times 200 \times 5 = 528000000$.

Work of the engine an hour $= 33000 \times 66 \times 60 = 130680000$;

$$\frac{528000000}{130680000} = 4 \cdot 04 \text{ hours.}$$

In this case $v = 36 \cdot 3$ ft. a second, and $\frac{W}{g} = \frac{200 \times 2240}{32 \cdot 2}$;

$$\therefore \quad f s = \frac{W}{g} \times \frac{v^2}{2} = 9166539 \text{ units of work.}$$

This work is conserved in the train, and exists in the train independent of the power of the engine and of the opposing resistances.

The following summary of experiments made to test the retarding power of different railway

brakes is taken, with some alterations and explanations, from a paper by W. Fairbairn, printed in the 'Proceedings of the Institution of Civil Engineers,' vol. xix. Suppose a train impelled by a locomotive engine until it attains a uniform velocity v in feet a second; that then the brakes are applied, and the train brought to a stand after passing a distance s in feet: it is required to find a measure of the force by which the momentum has been destroyed. Inasmuch as the brakes act by friction, which may be considered, with sufficient accuracy, to be uniform throughout the operation of braking, the train may be assumed to be stopped by a uniformly retarding force acting through the space s. If the retarding force in this case is called f, consisting mainly of the friction of the braked wheels, and, for simplicity, including also the friction of the axles, resistance of the air, and other constant resistances, then

$$f = \frac{v^2}{2\,s}. \qquad [1]$$

But supposing, as is generally the case, that the retarding force of the brakes is proportional to a part of the weight of the train only, that is, that the retarding force generated varies as the weight on the rubbing surfaces, and supposing the brakes to be applied to a few carriages only, putting w for the weight of the brake carriages in tons, and W for the weight of the train, then

$$f_1 = \frac{W\,v^2}{2\,w\,s}, \qquad [2]$$

which gives the retarding force to each unit of mass of the brake carriages.

It will be convenient to reduce this force to terms of weight instead of mass. Call f_2 the retarding force in pounds a ton weight of the brake carriages, then

$$f_2 = f_1 \times \frac{2240}{32\cdot 19} = 69\cdot 587\,f_1; \qquad [3]$$

that is, $f_2\,s = \dfrac{\frac{W}{w} \times 2244}{g} \times \dfrac{v^2}{2}$ = the units of work done in resisting the constant force (f_2) through a space (s); $\dfrac{g\,f_2}{2240}\,s = \dfrac{W}{w} \times \dfrac{v^2}{2} = f_1\,s$, and $\dfrac{w}{W} \times \dfrac{g\,f_2}{2240}\,s = \dfrac{v^2}{2} = f\,s$. v and s are variables, but W, w, g, are constants.

Again, supposing that, instead of being on a level line, the brakes are applied on an incline. Then the action of gravity will cause the train to go farther, if it is descending the incline, or to stop sooner, if ascending, than if the line was level; and gravity is a uniformly accelerating or retarding force, as the friction of the carriages. Hence the net result in distance and velocity of a train stopped on an incline may be supposed to arise from two forces: f, a retarding force dependent on the friction of the braked wheels; and ϕ, a retarding or accelerating force dependent on gravity, and assisting or opposing the action of f, according as the incline rises or falls; thence

$$f \pm \phi = \frac{v^2}{2\,s}. \qquad [4]$$

Now, the value of ϕ in terms of the inclination θ of the plane to the horizon is known, for if g be the velocity generated by the gravity in one second, $\phi = g$ sin. θ; or putting z for the vertical height fallen through by the train between the time of applying the brakes and stopping the train, $\phi = g\,\dfrac{z}{s}$;

$$\therefore\quad f = \frac{v^2}{2\,s} \pm g \text{ sin. } \theta = \frac{v^2}{2\,s} \pm g\,\frac{z}{s};$$

$$\text{or,}\quad f = \frac{\frac{1}{2}\,v^2 \pm g\,z}{s}, \qquad [5]$$

$$f_1 = \frac{W}{w} \times \frac{\frac{1}{2}\,v^2 \pm g\,z}{s}, \qquad [6]$$

$$f_2 = \frac{2240}{g} \times \frac{\frac{1}{2}\,v^2 \pm g\,z}{s} = 69\cdot 587\,f_1, \qquad [7]$$

where the + or − sign is to be adopted, according as the gradient falls or rises.

In the increase of the brake-power of trains, the principles hitherto most successfully employed have been,—first, the use of steam acting direct on the brakes; secondly, the connection of several of the ordinary form of brakes, so as to unite them under the control of a single brakesman; and thirdly, the introduction of brake apparatus connected with the buffers, so as to make the momentum of the train itself available in generating a retarding force.

M'Connell's brake, which is applicable only to the engine, consists of two wrought-iron sledges, each 48 in. in length and 4 in. in breadth, and turned up at the ends. These sledges are suspended from the lower side of the fire-box, between the driving and the trailing wheels of the engine. The pressure is placed on them by admitting steam from the boiler into two cylinders, each 9 in. in diameter, placed horizontally, one on each side of the fire-box, above the sledges, and forcing these latter down upon the rails by means of an elbow-joint. The pressure can be applied to either side of the pistons in the cylinders, according as the brakes have to be raised or depressed. The pressure of the sledges upon the rails, calculated from the pressure of the steam in Yolland's trials, would amount to about 6 tons. On the weighing machine, however, the actual pressure was found to vary from 4 tons to 9 tons, or a mean of about 7 tons; and these anomalies Yolland was unable to solve. The principal advantage of this brake appears to be that it is immediately applied without exertion, and is under the control of the engine-driver, who in

most cases is the first to perceive any obstruction on the line. It will be seen, however, that although efficiently generated, the amount of retardation caused by this brake is comparatively small, and, as Colonel Yolland concludes, insufficient to prevent collision in those cases in which its use would be specially desirable.

Newall's and Fay's brakes, which in their present condition are identical in principle, are distinguished from other brakes by this—that two or more carriages, or, if necessary, the whole train, are fitted with brake-blocks, all of which are brought under the direction of one guard by means of a longitudinal shaft, which transfers the motion of the guard's wheel to the brakes throughout the whole length of the train. In this way a great increase of retarding power may be obtained proportional to the weight of the carriages to which brakes are applied, and with this further advantage, that the retarding force is distributed equally throughout the train, instead of being accumulated at either end, and thus the shock upon the wheels and axles is much diminished. Newall and Fay have also adopted a partially self-acting apparatus of springs, by means of which the brakes are applied throughout the length of the train on the simple release of a catch by a guard.

In Newall's brake, the motion of the guard's or the engine-driver's wheel, since either or both of these may have the control of the brakes, is transferred, through the medium of a short vertical shaft in the van or tender, to the longitudinal shaft placed beneath the carriages of the train, by a pair of bevel-wheels, or by a spur-wheel and pinion. The longitudinal shaft passes either beneath the centre or at one side of the carriage, under the framework; and it is connected by simple, but very effective, jointed couplings between each pair of carriages, so as to permit the free action of the buffers, and the rise and fall of the carriages with the inequalities of the line. Near to the middle of the carriage a bevel-wheel is fixed on the longitudinal shaft, which is toothed into a similar one on a short cross-shaft, carrying also a spur-pinion geared into a horizontal rack. Thus, on revolving the guard's wheel, this rack is drawn back, withdrawing at the same time the principal arm of the rocking-shaft, at the centre of the carriage, and compressing a spring placed on the other side, to both of which the rack is attached by a simple connecting-rod. In this position the brake-blocks are off the wheels, and the brake is ready for use. If the bevel-wheel or pinion in the guard's van, or tender, is now released, or lifted out of gear by a lever or treadle, the springs throughout the train will force back the arm of the rocking-shaft, which carries the levers that press the brake-blocks on the wheels. If it is required to put on the brakes harder, and to skid the wheels, the treadle is again released by the guard, and the pressure increased by revolving the wheel in the ordinary way. In other words, Newall and Fay provide a number of springs, or in some cases weights, under each carriage, in which is stored up, ready for instantaneous use, a stock of brake-power, derived from the one guard acting through a longitudinal shaft, communicating with every brake by means of an arrangement of spur-wheels and pinions. From this it will be seen that on any emergency the retarding force may be instantly employed by simply releasing a catch, which permits the brake-blocks to be forced upon the wheels by the springs throughout the train.

In the class of brakes in which greater retarding power is obtained by increasing the number of braked carriages and combining their action, the systems just described appear the best and most comprehensive hitherto adopted. Fairbairn mentions that he received from E. W. Watkin the details of some experiments on an auxiliary brake carriage designed upon a different plan. In this case, an ordinary brake arrangement is employed, with a double elbow-joint, to which a long vertical lever is attached, moving in an arc against the side of the van. A rope from the end of this lever is conveyed to the tender, or the guard's van, and is attached to a drum on the axis of the ordinary guard's wheel. Hence, when the guard or the fireman revolves his wheel to put on his own brake, the rope coils upon the drum, drawing back the lever, and thus putting on the auxiliary brakes at the same time.

Belonging to the third class of brakes before enumerated, in which the momentum of the train itself is employed in generating the retarding force, there is only the brake of M. Guérin, which is entirely self-acting, and is brought into use by the recoil of the buffer-rods, when, by the application of the tender-brake, a retardation has been caused in front. Yolland thus describes this brake:—The buffer-rods at the after end of the carriage abut against a spring that extends across its width; one buffer-rod acting against each end of the spring. This spring, instead of being fixed against the under-framing of the carriage or the brake-van, is movable in a groove. On one side the centre of the spring is secured to the draw-bar, and on the other it is attached to the arm of a short lever, fixed almost vertically over the rocking-shaft; so that when the buffers are pressed in by the sudden check to the velocity—caused by shutting off the steam, by the application of the tender-brake in front, and by the momentum of the train in the rear—the buffer-spring is carried forcibly against the lever, the rocking-shaft is turned, and the brake-blocks are forced against the peripheries of the wheels. The brakes are prevented from being put on when a train is required to be shunted, by a cross-head or stop. But this provision interferes with the application of the brakes when the train is in motion at a low velocity. For such a speed it is assumed the tender-brake will be sufficient.

These are the brakes upon which the experiments were made, and the results tabulated and classified.

Newall's and Fay's Continuous Brakes.—In carrying out the views of the Directors of the Lancashire and Yorkshire Railway, Fairbairn arranged, in the first place, for a series of experiments on the Oldham incline, where two similar trains of carriages, one fitted throughout with Newall's and the other with Fay's brakes, were started alternately. After passing over a measured distance by the action of gravity, the brakes were applied, and the distance within which the trains were respectively brought up was carefully ascertained, as giving the measure of the brake-power of the trains. Each train consisted of three weighted carriages, and they were started by simply releasing a stop. Having descended, by gravity, a previously-measured distance,

with a uniformly accelerated velocity, they passed over a *fog-signal*, which gave notice to the guard to put on the brakes. Then the train having been brought to a stand, the distance from the point at which the train stopped to the *fog-signal* was measured back, and the train was dragged up the incline for another trial. Unfortunately, the day on which these experiments were made proved misty and foggy, with rain at intervals, so that the rails were in the worst condition for facilitating the stopping of the trains. The significance of this fact will be seen on comparing these results with later ones obtained in dry weather.

TABLE I.—EXPERIMENTS WITH NEWALL'S AND FAY'S RAILWAY BRAKES ON THE OLDHAM INCLINE, FEBRUARY 6, 1859.

Weather foggy and wet; gradient falling 1 in 27; weight of trains, 26 tons 10 cwt. each; no engine attached.

Fay's Flap-Brakes.					Newall's Slide-Brakes.				
No.	Time of Running.		Distance Run.		No.	Time of Running.		Distance Run.	
	Before Braking.	After Braking.	Before Braking.	After Braking.		Before Braking.	After Braking.	Before Braking.	After Braking.
	seconds.	seconds.	yards.	yards.		seconds.	seconds.	yards.	yards.
1	35	..	150	153	1	35	14	150	281
2	40	13	200	250	2	40	16	200	336
3	48	14	300	360	3	48	17	300	459
4	58	15	400	499	4	56	25	400	608
5	59	12	400	326	5	56	14	400	371
6	62	25	500	739	6	62	19	500	663
7	72	17	600	575	7	68	17	600	545
..	..	..	..	..	8	63	32	500	798

In experiment No. 8 the self-acting part of the brake only was employed.

In these experiments the whole of the wheels were sledged, or skidded, before the train was stopped. The self-acting arrangement of springs was fitted to Newall's carriage alone. In the later experiments it was adopted also by Fay.

Taking the mean of the number of seconds required in braking each train, in experiments Nos. 2, 3, 4, 5, 6, and 7, which were made under precisely corresponding circumstances in the case of each brake, and at similar velocities, it is found that the train was brought to a stand:—By Newall's brake, in 2·16 seconds; by Fay's brake, in 19·2 seconds; or about $2\frac{1}{2}$ seconds of time in favour of Fay's.

It will, however, be advisable to ascertain the precise value of the retarding force in each case by the formulæ already given. To effect this, the initial velocity of the train at the instant of applying the brakes must first be ascertained. For this purpose the least objectionable formula and at the same time the most simple is

$$v = \frac{2\,s}{t} \qquad [8]$$

for taking the mean velocity between o, and $v = \frac{v}{2}$ and $\frac{v}{2}$ multiplied by t second = the distance s; $\therefore\ \frac{v}{2} \times t = s$; where v is the velocity in feet per second; s is the distance run, in feet; and t is the time of running, in seconds. From this formula the following initial velocities of the train, in feet per second, in the preceding experiments, are obtained:—

No.		Fay.			Newall.	No.		Fay.			Newall.
1	..	25·71	..	..	25·71	5	..	40·66	..	..	42·85
2	..	30·	..	..	30·	6	..	48·38	..	..	48·38
3	..	37·50	..	..	37·50	7	..	50·	..	..	52·94
4	..	41·37	..	..	42·85	8	..	—	..	..	47·61

Hence, by equation [6], since in this case $\frac{W}{w} = \frac{26\cdot5}{26\cdot5} = 1$, and therefore $f = f_1$, and $f_1 = \frac{\frac{1}{2}\,v^2 + g\,s}{s}$, the relative values of each description of brake, and their comparative efficiency in each trial, may be derived. The retarding force of each brake is found to be as follows:—

No.			Fay.		Newall.	
1	..	..	1·9115	Mean 1·8538.	1·3246	Mean 1·7436.
2	..	..	1·7922		1·6388	
3	..	..	1·8432		1·7030	
4	..	..	1·7645		1·6946	
5	..	..	2·0280		2·0152	
6	..	..	1·7205		1·7811	
7	..	..	1·9167		2·0480	

Giving, as in the previous comparison, the advantage to Fay, in the proportion of 1·8538 to 1·7436, or as 1051 to 1000. The entire agreement of the results among themselves, and with the preceding comparison derived from the time, is sufficient evidence of the practical accuracy of the formula of reduction. The brakes stand, in these experiments, very nearly on an equality of merit.

The experiments in the next Tablo were made at Southport, npon a line more nearly level. The speed was obtained by means of a locomotive engine, which was detached, at the instant of applying the brakes, by a slip-coupling. The velocity, which was maintained uniform over the last half-mile, was measured by noting the time required to pass two fog-signals, placed half a mile apart. The brakes, in every trial, were applied almost instantaneously, after the report of the second fog-signal, and the distance was measured after the train had come to a state of rest.

TABLE II.—EXPERIMENTS WITH NEWALL'S AND FAY'S RAILWAY BRAKES, ON THE LINE BETWEEN LIVERPOOL AND SOUTHPORT, JANUARY 7, 1859.

Weather fine and frosty; gradient rising 1 in 485; weight of trains, 26 tons 10 cwt. each.

FAY.					NEWALL.				
No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles an Hour.	Velocity, in Feet, a Second.	Distance of Pulling up, in Yards.	No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles an Hour.	Velocity, in Feet a Second.	Distance of Pulling up, in Yards.
1	42	42·85	62·86	184	1	31	58·06	85·16	240
2	40	45·	66·	206	2	30	60·	88·	Lost,
3	34	52·94	77·65	272		as also another experiment.			
4	31½	37·14	83·81	313					
5	30	60·	88·	329	Engine alone	30	60·	88·	960

The second experiment with Newall's brakes failed, in consequence of tho guard applying tho brakes too soon; and a third was lost from tho fracture of the slip-conpling.

When these results are reduced by the same formula, the following values of f_1, representing the efficiency, or retarding force of each brake, are obtained:—

No.	Fay.		Newall.
1	3·5125	Mean 3·6256.	4·97
2	3·4579		
3	3·6274		
4	3·6738		
5	3·8566		

These experiments give a superiority in favour of Newall's brakes, in the proportion of 4·97 to 3·6256, or as 1378 to 1000.

The value of the retarding force, f, for the tender-brake, derived from the last experiment, is 1·2791, and reducing this, in proportion of the weight of the tender to the weight of the engine and tender, it becomes $f_1 = 4·3455$.

At this period, Fay requested permission to attach a self-acting apparatus to his brakes, as he considered they were not fairly matched against those of Newall, when applied by hand. The experiments were, therefore, postponed for two months, to enable Fay to effect this alteration. They were again resumed on the 14th of April, 1859.

TABLE III.—EXPERIMENTS WITH NEWALL'S AND FAY'S RAILWAY BRAKES, ON THE LINE BETWEEN LIVERPOOL AND SOUTHPORT, APRIL 14, 1859.

Weather, dry during the first, with a slight shower during the remaining experiments; gradient falling 1 in 3453; weight of trains, 27 tons 6 cwt.

FAY.					NEWALL.				
No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles an Hour.	Velocity, in Feet a Second.	Distance of Pulling up, in Yards.	No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles an Hour.	Velocity, in Feet a Second.	Distance of Pulling up, in Yards.
1	56½*	31·8	46·7	121½	1	58	31·	45·5	101
2	53¾	33·4	49·1	124	..	..	..	..	..

* Engine attached and tender-brake applied.

Rednicing the results, as before: $f_1 = 3·2329$ with Fay's brake; $f_1 = 3·4161$ with Newall's brake; $f_1 = 2·9956$ with Fay's brake and tender-brake.

Here the superiority lies with Newall, in the ratio of 1056 to 1000. The experiment with the engine attached, when reduced in the ratio of tho weight of the train to the weight on the wheels braked, gives $f_1 = 4·84$.

It will be observed that as the value of the retarding force of the brakes is here obtained in

terms of the coefficient of friction, for the rubbing surfaces, the efficiency of the brake varies with the condition of the weather. Thus the mean of the Oldham experiments gave a retarding force of 1·7987 ft. per second; the mean of the first experiments at Southport gave 4·2978, and the mean of the second 3·3245. On each day the experiments were consistent with one another, but they differed widely, on different days, from the change in the condition of the rubbing surfaces. At Oldham, the experiments were made with the rails in a greasy condition, from fog; at Southport, in the later of the two trials, with the rails slightly wet, and in the earlier, with rails dry, and in the best condition for braking. This is in accordance with the experiments of Morin on the friction of iron on iron, in which it was found that the coefficient of friction varied from 0·05 to 0·3, according as the surfaces were greasy, wet, or dry. This consideration must be borne in mind in estimating the results; and together with some improvements in the adjustment of the brakes, and the introduction of increased power, from time to time, will explain the discrepancies which may be found, on comparing the results obtained at different periods of the trials.

The remaining experiments upon the self-acting brakes were all made under uniform and favourable conditions; the weather was fine, and the wind blew each day from the west or the north-west. The results, also, are uniform for these days, and there can, therefore, be no error in placing these experiments in the same Tables, and averaging them together. This classification will, therefore, be adopted as more convenient, and they will be arranged under the following heads:—

1. Experiments on the friction of the carriages.
2. Experiments with slide-brakes, with the engine detached.
3. Experiments with flap-brakes, with the engine detached.
4. Experiments with the engine attached to the train.

Experiments on the Friction of the Carriages.—These experiments were made by running the train, as before, past two fog-signals, half a mile apart, to obtain the velocity, detaching the engine at the second fog-signal, and allowing the train gradually to come to rest.

TABLE IV.—EXPERIMENTS WITH NEWALL'S AND FAY'S RAILWAY BRAKES, ON THE LINE BETWEEN LIVERPOOL AND SOUTHPORT, JUNE 2, 1859.

	Time of Running ½ Mile, in Seconds.	Speed, in Miles an Hour.	Distance run, after applying Brakes, in Yards.	Time of Running, after applying Brakes, in Seconds.	Height fallen through by Train from inclination of Line, in Feet.
Fay	40·	45·	4840	430	7·06
Newall	44·5	40·45	6380	780	13·91

Reducing as before, the normal friction of the carriages, $f = f_1$, is found to be,—Fay, 0·16565; Newall, 0·10961; and therefore f_2, or the friction per ton weight of the carriages, is,—Fay, 11·527 lbs.; Newall, 7·627 lbs.; mean, 9·577 lbs.

This shows that there is a considerable difference between the friction of the two sets of carriages; and a small correction should therefore be made, in the reductions of the experiments on brakes, in favour of Newall, if perfect accuracy were required. The correction, however, does not exceed one-sixtieth of the retarding force of the brakes, and may be neglected without appreciable error. These experiments were made with carriages fitted with slide-brakes, and the friction of those with flap-brakes was not determined.

In an experiment recorded in Yolland's Report, the friction, derived in the same way, for a train of carriages fitted with Newall's brakes, and attached to an engine and tender, amounted to 11·4 lbs. per ton. This, when allowance is made for the greater friction of the engine, nearly agrees with Fairbairn's results.

TABLE V.—EXPERIMENTS WITH NEWALL'S AND FAY'S SLIDE-BRAKES AT SOUTHPORT, MAY, 1859.

NEWALL.					FAY.				
No.	Time of Running ½ Mile, in Seconds.	Speed, in Miles an Hour.	Velocity, in Feet a Second.	Distance of Pulling up, in Yards.	No.	Time of Running ½ Mile, in Seconds.	Speed, in Miles an Hour.	Velocity, in Feet a Second.	Distance of Pulling up, in Yards.
2	55	32·72	48·	56⅔	2	51	35·29	51·76	56
4	49	36·73	53·87	77	4	41	43·9	64·39	98
6	41½	failed	..	..	5	36	50·	73·33	129
7	41	43·9	64·39	136	6	33	54·54	80·	114
8	39	46·15	67·69	140⅔	7†	33	54·54	80·	161⅔
9	34	52·94	77·64	205⅓	9‡	47½	37·89	55·58	97
10*	33	54·54	80·	192	10‡	30	60·	88·	204⅔
11†	38	47·37	69·47	260⅓	11‡	30	60·	88·	214
12‡	33½	53·73	78·8	222	..	..	..	..	..
13	28½	63·16	92·63	273	..	..	..	..	..

* Self-action only. † Brakes not applied at the proper time.
‡ Train consisting of two carriages, and weighing 18 tons 4 cwt. In the other experiments there were three carriages, weighing 27 tons 6 cwt.

Experiments with Slide-Brakes, with the Engine detached from the Train.—The following experiments were made between the Birkdale and Ainsdale stations, on the line between Liverpool and Southport. As before, the engine was attached by a slip-coupling to the train. At the quarter and the three-quarter mile posts from Ainsdale, fog-signals were placed, and the time of passing between these, being accurately observed by stop-watches, gave the average speed of the train. At the second fog-signal, the slip-coupling was unfastened, and the brakes applied, instantly on hearing the report. The assistant, Unwin, and other persons, were placed in the guard's van, to prevent the premature application of the brakes; and others on the engine with the driver, to see that there was no change of velocity in passing over the half-mile in which the speed was observed. The line where these experiments took place rose, for 500 ft. from the first fog-signal, with a gradient of 1 in 1087, and then fell for upwards of a mile, with a gradient of 1 in 3543, a fall so slight, in the short space in which the trains were brought to rest, that it cannot appreciably affect the results; and in the reductions the line has been considered as level.

The trains with which these experiments were made consisted of three heavily-weighted carriages, each with brakes to every carriage, except in the two last experiments, when, in consequence of an accident to one of Newall's carriages, the trains were reduced to two. The carriages were loaded with iron rail-chairs, so as to weigh 9 tons 2 cwt. each.

The power of these continuous brakes was well exemplified upon the 18th May, when Fay's guard inadvertently applied the brakes whilst the train was running at a comparatively slow velocity; the strong coupling-hook which united the tender to the guard's van was instantly snapped, and the train brought to a stand.

Making a reduction of the preceding results, the following values of $f = f_1$, representing the comparative retarding powers of the brakes in each case, are arrived at:—

Fay.		Newall.	
7·9749	Mean 6·7030.	6·7765	Mean 5·4984.
7·0512		6·2813	
6·9480		5·0810	
7·4074		5·4292	
6·5979		4·8929	
5·3076		4·6625	
6·3062		5·2385	
6·0311		5·5555	

In this case the brakes of Fay exhibit a superiority in the ratio of 6·7030 to 5·4984, or as 1215 to 1000; or making a correction, as above stated, for the friction of the carriages, the relative efficiency of Fay's and Newall's brakes would stand in the ratio of 6·553 to 5·4084, or as 1210 to 1000.

Experiments with Flap-Brakes, with the Engine detached.—These experiments, Table VI., were made in precisely the same manner as the last, the trains consisting of three carriages with brakes to each, loaded to 9 tons 2 cwt.

TABLE VI.—FLAP-BRAKES, ENGINE DETACHED.

Fay.					Newall.				
No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles an Hour.	Velocity, in Feet a Second.	Distance of Pulling up, in Yards.	No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles an Hour.	Velocity, in Feet a Second.	Distance of Pulling up, in Yards.
1	35	51·43	75·43	158¼	1	36	50·	73·33	132⅔
2	35	51·43	75·43	162⅔	2	36	50·	73·33	123
3*	32	54·54	80·	184	3*	35	51·43	75·43	192

* Self-action only.

Reducing the results, the comparative efficiency is:—

Fay.		Newall.	
5·9889	Mean 5·8718.	6·7560	Mean 6·3272.
5·8294		7·2870	
5·7971		4·9387	

In this case the superiority lies with Newall, in the ratio of 6·3272 to 5·8718, or as 1000 to 928.

Experiments with the Engine attached to the Train.—These experiments were made with slide-brakes, upon the same ground and in the same manner as the last experiments. The rails also were in the same dry condition. The only difference was that the engine and tender remained attached to the train, instead of being uncoupled, and the tender-brake was applied as rapidly as possible along with the other brakes.

Table VII.—Experiments with Newall's and Fay's Railway Brakes, with Engine not disconnected from Train.

Weight of engine, 24 tons; weight of tender, average 10 tons; weight of train, 27½ tons; weight of tank engine, 30 tons.

Fay.					Newall.				
No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles an Hour.	Velocity, in Feet a Second.	Distance of Pulling up, in Yards.	No.	Time of Running ¼ Mile, in Seconds.	Speed, in Miles an Hour.	Velocity, in Feet a Second.	Distance of Pulling up, in Yards.
1	56½	31·8	46·7	121⅓	1	53	33·96	49·81	124⅔
2	53	33·96	49·81	137	2	48½	37·11	54·43	169⅓
3	43	41·86	61·39	192⅓	3	43	41·86	61·39	221
4*	35	51·43	75·43	274	..	..	..	..	..

* Tank engine.

Reducing these results, the comparative retarding force is found to be:—

Fay.		Newall.	
2·9956 3·0184 3·2663	Mean 3·0934.	3·3169 2·9160 2·8422	Mean 3·0250.

where the efficiency of the brakes is almost identical. Fay having an advantage, in the ratio of 1022 to 1000.

From the above extended and somewhat laborious experiments, the following summary of results is derived:—

Table VIII.—General Summary of Results of Experiments with Newall's and Fay's Brakes.

	Average Number of Experiments.		Average Efficiency of Brakes.	
	Fay.	Newall.	Fay.	Newall.
Oldham Incline, Table I. ..	7	7	1·8538	1·7436
Southport " " II. ..	5	1	3·6256	4·9700
" " " III. ..	1	1	3·2329	3·1416
" " " V. ..	8	8	6·7030	5·4984
" " " VI. ..	3	3	5·8718	6·3272
" " " VII. ..	3	3	3·0934	3·0250

The general average from this Table gives, for the efficiency of Fay's brakes, 4·0634, and for that of Newall's 4·1650, showing a slight superiority in favour of the latter.

The following conclusions seem borne out by these experiments:—

1st. That with slide-brakes the greater number of experiments gave a manifest superiority to Fay's.

2nd. That with flap-brakes there was a decided advantage on the side of Newall.

3rd. That when the train was braked, with the engine attached, the results were uniform; neither Fay's brakes nor Newall's gaining any decided superiority.

During the whole of these trials there was a strong feeling of rivalry, which rendered necessary the greatest caution, in order to prevent any interference, which might modify and vitiate the results. To reconcile these differences, and to obtain correct returns, Unwin was employed to take charge of the train, and to see that the brakes were applied at the right time; also to register the velocity of the train, and the distance of pulling up, during each experiment. There is therefore every reason to believe that the results recorded are a strict expression of the efficiency of the brakes, at their respective times of trial.

Yolland's Experiments with Newall and Fay's Railway Brakes.—It may be interesting to compare with these results the earlier experiments obtained by Colonel Yolland, on the same class of brakes, and under somewhat similar conditions of trial, as detailed in his Report to the Board of Trade, dated the 12th June, 1858. These results do not appear to have been reduced, hitherto, to any common standard of comparison. But as they embrace a wider range of circumstances of gradient, weather, weight, &c., than in Fairbairn's experiments, they will instructively test the method of reduction employed.

In the experiments on the Accrington incline the trains weighed 72 tons each, and consisted of six weighted carriages, used in all the experiments, and of three carriages fitted with Newall's, and three with Fay's brakes, respectively, and employed alternately. The required velocity was obtained by permitting the carriages to descend a distance of from three-quarters of a mile to a mile along the incline, which falls at the rate of 1 in 38 to 1 in 40. The initial velocity at the instant of applying the brakes was ascertained by observing the time required to traverse the quarter of a mile immediately preceding; and the mean velocity over this distance is used in

the reductions as the initial velocity of the train, although it is slightly below the real speed, at the instant of braking.

TABLE IX.—EXPERIMENTS ON THE ACCRINGTON INCLINE, WITH NEWALL'S AND FAY'S BRAKES, FEBRUARY 27, 1858. Weather fine.

No.		Velocity, in Feet a Second.	Gradient falling —.	Distance of Braking, in Yards.	Remarks.
2	Newall ..	69·47	— 1 in 39	1587	Heavier train.
3		52·8	— 1 in 39	777	Three continuous brakes.
4		48·9	— 1 in 39	822	
5		28·7	— 1 in 40	414	
6		69·47	— 1 in 39	1114	
7		62·86	— 1 in 40	1208	
9		30·7	— 1 in 39	430	
10	Fay	60·	— 1 in 39	923	

Reducing the results in Table IX., the retarding force is:—

Newall.		Fay.
1·0275	Mean 1·3231.	1·4754
1·4233		
1·3102		
1·1363		
1·5285		
1·3705		
1·1700		

It will be remarked that in these experiments the brakes were applied to a part of the train only. Hence, for comparison with the Southport experiments, a reduction must be made, to the condition of trains with brakes throughout, by the formula [6] already explained in that way,

$$f_1 = \frac{W}{w} f.$$

The retarding force in terms of the mass of the carriages actually braked is:—

Newall.		Fay.
3·7955	Mean 3·5516.	3·9345
3·4940		
3·0301		
4·0759		
3·6547		
3·1200		

Showing an advantage to Fay in the ratio of 1107 to 1000. But a comparison is here scarcely fair, seeing the disproportion in the number of experiments with each brake.

TABLE X.—EXPERIMENTS ON THE ACCRINGTON INCLINE, WITH NEWALL'S AND FAY'S BRAKES, FEBRUARY 28, 1858. Weather misty.

No.		Velocity, in Feet a Second.	Gradient, falling —.	Distance of Braking, in Yards.	Remarks.
11	Fay	66·	— 1 in 39	2060	Three continuous brakes.
13		62·86	— 1 in 39	1660	
16		50·77	— 1 in 39	1070	
17		35·67	— 1 in 40	492	
12	Newall ..	60·	— 1 in 39	2142	
14		60·	— 1 in 39	1754	
15		50·77	— 1 in 39	1450	
18		69·47	— 1 in 132	880	Tender and ditto.

The results in Table X. show that the mean of the retarding force is:—

Fay.		Newall.	
1·178	Mean 1·220.	1·105	Mean 1·131.
1·221		1·167	
1·227		1·122	
1·257			

Or with brakes throughout:—

Fay.		Newall.	
3·141	Mean 3·255.	2·946	Mean 3·017.
3·256		3·112	
3·272		2·992	
3·352			

Giving a slight advantage to Fay, in the ratio of 1070 to 1000.

TABLE XI.—EXPERIMENTS WITH NEWALL'S BRAKES, BETWEEN LIVERPOOL AND PRESTON, FEBRUARY 22, 1858.

Train of carriages weighing 83 tons 18 cwt.; engine, 29 tons 2 cwt.; tender, 13 tons 4 cwt.

No.		Velocity, in Feet a Second.	Gradient, rising +, falling −.	Distance of Braking, in Yards.	Remarks.
1	Newall ..	57·39	− 1 in 135	285	Tender and six brakes.
2		48·88	− 1 in 180	208	
3		66·00	+ 1 in 135	206	
4		45·52	+ 1 in 168	246	Tender and self-action of six brakes.
6		57·39	− 1 in 150	276	Tender and six brakes.
7		48·88	− 1 in 130	204	

Reducing as before, these data give .. .. ..
$$\left\{\begin{array}{l} f = 2\cdot165 \\ f = 2\cdot095 \\ f = 3\cdot285 \\ f = 2\cdot204 \\ f = 2\cdot201 \end{array}\right\} \text{Mean } 2\cdot390;$$

or, reduced in the ratio of the weight on the wheels braked to the weight of the train .. ..
$$\left\{\begin{array}{l} f_1 = 4\cdot304 \\ f_1 = 4\cdot164 \\ f_1 = 6\cdot530 \\ f_1 = 4\cdot381 \\ f_1 = 4\cdot375 \end{array}\right\} \text{Mean } 4\cdot671.$$

This agrees with the value $f_1 = 3\cdot5516$, obtained in the first experiments at Accrington, with the rails dry, and is in excess of the value $f_1 = 3\cdot017$, obtained with the rails wetted by the mist.

For experiment No. 4, with the self-action of the brakes alone, $f = 1\cdot211$, or about one-half the full brake-power.

TABLE XII.—EXPERIMENTS BETWEEN PRESTON AND LIVERPOOL, WITH NEWALL'S RAILWAY BRAKES, FEBRUARY 22, 1858.

Weight of train, 101 tons 1¾ cwt.; weight on brakes, 71 tons 19½ cwt.

No.		Velocity, in Feet a Second.	Gradient, rising +, falling −.	Distance of Pulling up, in Yards.	Remarks.
8	Newall ..	73·33	0	196	Tender and seven continuous brakes.
9		57·39	+ 1 in 402	130	
10		44·	0	107	
11		60·	− 1 in 120	167	

Reducing these results .. ..
$$\left\{\begin{array}{l} f = 4\cdot567 \\ f = 2\cdot975 \\ f = 3\cdot015 \\ f = 4\cdot118 \end{array}\right\} \text{Mean } 3\cdot668;$$

or, when the train is braked throughout .. .. ..
$$\left\{\begin{array}{l} f_1 = 6\cdot406 \\ f_1 = 4\cdot173 \\ f_1 = 4\cdot229 \\ f_1 = 5\cdot776 \end{array}\right\} \text{Mean } 5\cdot146.$$

This would seem to indicate that the brakes act more efficiently, the more nearly they are applied throughout the whole train.

TABLE XIII.—EXPERIMENTS BETWEEN LIVERPOOL AND PRESTON, WITH NEWALL'S BRAKES, FEBRUARY 23, 1858.

No.		Velocity, in Feet a Second.	Gradient, rising +, falling −.	Distance of Pulling up, in Yards.	Remarks.
1	Newall ..	77·65	− 1 in 204	314	All the brakes.
2		73·33	0	179	
3		52·8	0	183	All but the tender.
4		73·33	− 1 in 132	227	All the brakes.
5		66·	+ 1 in 135	189	
6		73·33	0	249	
7		62·86	− 1 in 150	208	
8		44·	− 1 in 700	138	
9		77·65	− 1 in 120	235	

Reducing .. .. $\left\{\begin{array}{l} f = 3{\cdot}3582 \\ f = 5{\cdot}0068 \\ f = 3{\cdot}7041 \\ f = 4{\cdot}0797 \\ f = 3{\cdot}5992 \\ f = 2{\cdot}9516 \\ f = 2{\cdot}2922 \\ f = 4{\cdot}0081 \end{array}\right\}$ Mean 3·6249;

or, when further reduced in the ratio of the weight of the whole train to the weight on the wheels braked .. $\left\{\begin{array}{l} f_1 = 3{\cdot}9660 \\ f_1 = 5{\cdot}9130 \\ f_1 = 4{\cdot}3745 \\ f_1 = 4{\cdot}8181 \\ f_1 = 4{\cdot}2506 \\ f_1 = 3{\cdot}4858 \\ f_1 = 4{\cdot}7335 \end{array}\right\}$ Mean 4·5057.

The preceding results obtained by Yelland are as follows:—

	Fay.	Newall.	
Engine detached	3·9345	3·5516	Dry.
	3·255	3·017	Wet.
Engine attached		4·671 5·146 4·505	Mean 4·774.

TABLE XIV.—EXPERIMENTS ON M'CONNELL'S STEAM SLEDGE-BRAKE, BETWEEN BLETCHLEY AND OXFORD, JANUARY 19, 1858.

The engine weighed 29 tons; the tender, 14 tons 10 cwt.; the carriages, 102 tons 9 cwt.; the guards' vans, 10 tons 4½ cwt.; steam-sledges assumed at 7 tons 2 cwt.

No.		Velocity, in Feet a Second.	Gradient, rising +, falling −.	Distance of Pulling up, in Yards.	Remarks.
1	M'Connell's steam-brake.	27·5	+ 1 in 150	430	None.
2		32·19	+ 1 in 142	285	Steam and guard's.
3		19·35	+ 1 in 142	163	Guard's.
4		52·8	− 1 in 214	590	All.
5		60·	− 1 in 149.	870	Steam and tender.
6		48·88	− 1 in 209	673	All.
7		36·67	− 1 in 1430	623	Steam.
8		55·	− 1 in 163	880	All.
9		55·	0	763	Tender and guard's.
10		57·39	0	1320	Steam.
11		52·8	− 1 in 2211	496	All.
12		60·	0	540	All.
13		55·	+ 1 in 2211	345	All.
14		47·14	0	538	Tender and guard's.
15		47·14	− 1 in 452	388	All.
16		62·86	+ 1 in 163	669	All.
17		57·39	0	880	Tender and guard's.
18		55·	+ 1 in 209	1194	Steam.

Reducing these results:—

No.		No.	
2	$f = 0{\cdot}03793$	11	$f = 0{\cdot}93677$
3	$f = 0{\cdot}01562$	12	$f = 1{\cdot}11111$
4	$f = 0{\cdot}93791$	13	$f = 1{\cdot}42800$
5	$f = 0{\cdot}90567$	14	$f = 0{\cdot}64824$
6	$f = 0{\cdot}74567$	15	$f = 1{\cdot}02560$
7	$f = 0{\cdot}38224$	16	$f = 0{\cdot}78690$
8	$f = 0{\cdot}77041$	17	$f = 0{\cdot}62379$
9	$f = 0{\cdot}66076$	18	$f = 0{\cdot}42225$
10	$f = 0{\cdot}41586$		

Separating those experiments which were made on different brakes, and taking the mean of those made on the same, the value of each brake respectively is as follows:—

For the guard's brake .. .. $f = 0{\cdot}1562$
" tender-brake .. .. $f = 0{\cdot}4989$
" steam-brake .. .. $f = 0{\cdot}4373$
" steam and tender brakes .. .. $f = 0{\cdot}9057$
" steam and guard's brakes .. .. $f = 0{\cdot}3793$
" guard's and tender brakes .. .. $f = 0{\cdot}6443$
guard's, steam, and tender brakes .. .. .. $f = 0{\cdot}9678$

These numbers represent the actual proportion of the brake-power supplied in the experiments by each brake or set of brakes. The efficiency of the brakes in relation to the weight upon them is:—

For the guard's brake .. .. $f_1 = 2 \cdot 2268$
„ tender-brake .. .. $f_1 = 5 \cdot 0216$
„ steam-brake .. .. $f_1 = 9 \cdot 1176$
„ steam and tender brakes .. .. $f_1 = 6 \cdot 1197$
„ steam and guard's brakes .. .. $f_1 = 3 \cdot 1930$
„ guard's and tender brakes .. .. $f_1 = 3 \cdot 8014$
„ guard's, steam, and tender brakes .. .. $f_1 = 4 \cdot 4365$

This shows that, in proportion to the weight upon it, a sledge-brake, which can be applied instantly, acts most efficiently.

Colonel Yolland's Experiments with M. Guérin's Self-acting Brake.—The train in the first four experiments consisted of an engine, tender, and nineteen carriages, two being fitted with M. Guérin's brakes. The total weight of the train was 151·88 tons. In the remaining experiments two ordinary brake-vans were substituted for M. Guérin's, the total weight being then 152·8 tons.

TABLE XV.—EXPERIMENTS BETWEEN ERITH AND WOOLWICH, AUGUST 27, 1858.

No.		Velocity, in Feet a Second.	Gradient, rising +, falling −.	Distance of Pulling up, in Yards.	Remarks.
1	M. Guérin's brakes.	50·78	− 1 in 912	597	Tender and two Guérin brakes.
2		62·86	0	738	
3		57·39	0	552	
4		45·52	+ 1 in 912	395	
5	Ordinary brake-vans.	48·57	− 1 in 912	359	Tender and two ordinary brakes.
6		66·	0	593	
7		50·77	0	521	
8		52·8	+ 1 in 912	510	

Reducing these results:—

M. Guérin's Brakes.		Ordinary Brakes.	
0·075488	Mean 0·0870.	0·11300	Mean 0·1013.
0·089238		0·12243	
0·099445		0·08245	
0·083898		0·08757	

From these experiments, M. Guérin's brakes appear to be less efficient than two equally heavy brake-vans of the ordinary description, when used in conjunction with a tender-brake, in the ratio of 1165 to 1000.

The value of f_1 for the mean of these experiments gives:—

For M. Guérin's brake .. .. 0·5169
„ the guard's ordinary brake .. .. 0·5874

We do not pretend to know the reason why, but Guérin's brake gave better results when tried in France.

Experiments with Ingram's Auxiliary Brake, on the Manchester, Sheffield, and Lincolnshire Railway.—When these experiments were made, the weather was bad, rain falling the whole time. The train weighed 124 tons ½ cwt.; the tender, 17 tons; the carriages to which Ingram's brake was applied, 25 tons 17½ cwt.

TABLE XVI.—EXPERIMENTS WITH INGRAM'S BRAKES, OCTOBER 18, 1858.

No.		Velocity, in Feet a Second.	Gradient.	Distance of Pulling up, in Yards.	Time in Stopping, in Seconds.
3	Ingram's brake.	46·9	1 in 124	870	90
3		44·0	1 in 124	795	77
4		51·3	1 in 133	768	65
7	Tender ..	54·2	1 in 120	1320	134
9		46·9	1 in 120	1152	114

Reducing these results, on the assumption that the gradients were all falling ones:—

Ingram's Brakes. Tender-Brakes.

$$f = \left\{ \begin{array}{l} 0 \cdot 68096 \\ 0 \cdot 66545 \\ 0 \cdot 81870 \end{array} \right\} \text{Mean } 0 \cdot 7217. \qquad \left. \begin{array}{l} 0 \cdot 63921 \\ 0 \cdot 58646 \end{array} \right\} \text{Mean } 0 \cdot 6128.$$

Hence, f_2 = with Ingram's brake .. .. 3·4619
the tender-brake .. .. 4·4712

Ingram's brake thus shewing a somewhat less efficiency than the tender-brake.

It should be here observed that the work employed to move a body over a horizontal distance, added to the work due to the gravity in elevating the body a vertical height, is the same as that employed in moving the body on a curve joining the extreme points, since a curve may be supposed to be made up of a number of straight lines; hence the uniform work upon the whole curve will be equal to the uniform work done upon the horizontal projection, added to the work done in opposition to gravity in raising the body, no matter what form be given to the path described. See Byrne's 'Essential Elements of Practical Mechanics,' p. 276.

Reduction of the Retarding Force to Units of the Weight of the Brake Carriages.—In the preceding reductions it was found most convenient to know the retarding force in terms of the mass of the train. For practical purposes, however, it is convenient to state the retarding force in terms of the weight upon the brake carriages, and, to be guided by precedent in this matter, it seems best to state the retarding force in pounds to the ton weight on the braked wheels, that is, in the same terms as the normal friction of the train is usually stated. Calling, therefore, f_2 the mean resistance in pounds a ton, in the moving mass of all the forces tending to destroy motion, of which the principal is the friction of the brake, then $f_2 = f_1 \times \frac{2240}{32 \cdot 19} = 69 \cdot 587\, f_1$.

ORDINARY BRAKES.

	Retardation, in lbs. a ton, on Wheels Braked.	
Guard's van	154·9	Yolland.
Tender-brake	349·4	"
Tender and guard's brakes	264·5	"
Tender-brake	311·0	M. S. and L. Railway.

All the above results, with the exception of the last, were obtained in dry weather.

Tender-brake	302·4	Fairbairn.

NEWALL.

Tables.		Mean Retarding Force, in lbs. a ton weight, of Braked Carriages.	
I.	Slide-brakes (wet and foggy)	121·3	Fairbairn.
III.	" " (slightly wet)	237·7	"
II.	" " (dry and frosty)	345·8	"
V.	" " (dry and warm)	382·6	"
IV.	Flap-brakes (dry and warm)	440·3	"
IX.	" " (dry)	247·1	Yolland.
X.	" " (misty)	209·7	"
XI.	" " (dry)	325·4	"
XII.	" " (dry)	358·9	"
XIII.	" " (dry)	313·5	"

The mean of the experiments from Tables II., IV., and V., gives the retarding force at 389·6 lbs. per ton. The mean of Yolland's, from Tables IX., XI., XII., XIII., is 311·2 lbs.; or, omitting Table IX., 332·6 lbs. Bearing in mind that Fairbairn's results were obtained under circumstances of competition, and that there was in consequence the greatest care in the adjustment of the brakes, the above results agree sufficiently well. Hence also may be observed the very large diminution of the retardation of the brakes in wet and foggy weather. In wet weather the retardation does not appear to exceed 200 lbs. a ton; and in foggy weather, with the rails greasy, it appears that it may be reduced to 121 lbs., or nearly one-fourth of the maximum in dry warm weather.

FAY.

Tables.		Mean Retarding Force, in lbs. a ton weight, of Braked Carriages.	
I.	Flap-brakes (wet and foggy)	129·0	Fairbairn.
III.	" " (slightly wet)	224·9	"
II.	" " (dry)	252·2	"
IV.	" " (dry)	408·6	"
V.	Slide-brakes (dry)	466·4	"
IX.	" " (dry)	273·7	Yolland.
X.	" " (misty)	226·5	"

There the maximum retardation amounts to 466·4 lbs. a ton, or nearly one-fifth of the weight of the braked carriages. The mean of Tables II., IV., V., in dry weather, gives 375·7 lbs. a ton.

M'CONNELL'S STEAM-BRAKE.

Table XIV.	Mean Retardation, in lbs. a ton weight, on Wheels and Sledges Braked.	
Guard's van	154·9	Yolland.
Tender-brake	349·4	"
Steam-brake	634·4	"
Steam and tender brakes	425·8	"
Steam and guard's brakes	222·1	"
Guard's and tender brakes	264·5	"
Guard's, steam, and tender brakes	308·7	"

These reductions seem to show that, in proportion to the weight upon it, the sledge-brake is more efficient than any brake applied to the wheels. Of course it is not asserted that the sledge-brake could be employed in lieu of the present arrangement; but that it renders useful, in retarding the train, a larger proportion of the weight on it.

M. Guérin's Brake.

Table XV.

	Mean Retarding Force, in lbs. a ton, on Brake Carriages.	
M. Guérin's and tender brakes	35·9	Yolland.
Ordinary van and tender brakes ..	40·8	"

Both these brakes were, for some reason, acting inefficiently.

Ingram's Brake.

Table XVI.

	Mean Retarding Force, in lbs. a ton weight, of the Carriages Braked.	
Ingram's and tender brakes..	240·9	M. S. and L. Railway.

General Summary.

		Ratio of Weight on Brakes, to Retarding Force generated by them, or Mean Coefficient of Friction for each Brake.
Newall's (dry)	Fairbairn	from 0·1544 to 0·1965
" (wet)	Fairbairn	0·0542
Fay's (dry)	Fairbairn	from 0·1126 to 0·2082
" (wet)	Fairbairn	0·0576
Newall's (dry)	Yolland	0·1116
Fay's (dry)	Yolland	0·1020
Ingram's (wet)		0·1075
Guérin's (dry)		0·01048
M'Connell's steam-brake		0·28325

That is, the retarding force generated by these brakes varies from $\frac{1}{100}$ to $\frac{3}{10}$ of the weight of the carriages to which brakes are applied, and is ordinarily from $\frac{1}{10}$ to $\frac{1}{5}$.

This agrees very well with the deductions from experiments on the friction of metal on metal, which give for smooth surfaces a coefficient varying from 0·15 to 0·2, or nearly identical with the best experiments above reported.

Formulas.—To find the distance on a level line required to bring a train to a stand by braking:—

Let s = the distance of pulling up, in yards;
v = the velocity of the train, in feet per second;
w = the weight on the braked wheels, in tons;
W = the total weight of the train, in tons;
θ = the inclination of the incline to the horizon, if the train is on a gradient, so that if the incline rises 1 ft. in x ft., then $\sin. \theta = \frac{1}{x}$;
g = the action of gravity = 32·19.

Then, if the train is braked throughout, and on a level line, $s = \frac{v^2}{6 f_1}$; and if brakes are applied to a part of the train only, $s = \frac{v^2}{6 f_1} \times \frac{W}{w}$; or, if the train is on an incline,

$$s = \frac{v^2}{6 f_1 \pm 6 g \sin. \theta} \times \frac{W}{w},$$

where the + or − sign is to be taken, according as the incline falls or rises.

The value of the coefficient f_1 must be selected from the Tables of Experiments already given, that coefficient being selected which was obtained under circumstances most nearly approaching those of the case to be determined.

Thus, if the trains are stopped by the friction of their bearings, and so on, without the application of brakes, $f_1 = 0·13$ (mean), and $6 f_1 = 0·78$.

If the brakes are ordinary guard and tender brakes, applied together, $f_1 = 4$, and $6 f_1 = 24$, approximately.

For brakes, such as Newall's and Fay's, acting with maximum efficiency, $f_1 = 5·5$ to $6·5$, and $6 f_1 = 33·0$ to $39·0$.

Thus, supposing it is required to ascertain the distance in which a train weighing 60 tons, with brakes to 20 tons weight of the carriages, would be brought to rest, in ascending an incline of 1 in 27, at a velocity of 60 ft. a second; then taking $f_1 = 4$,

$$s = \frac{v^2}{6 f_1 + 6 g \sin. \theta} \times \frac{W}{w} = \frac{(60 \times 60)}{6 \times 4 + 6 \times 32·19 \times \frac{1}{27}} \times \frac{60}{20} = 116 \text{ yds.}$$

If the rails are wetted by rain, the value of the coefficients given above must be taken at one-third less, and if greasy, their value may be reduced by as much as one-half or three-fourths.

It is convenient, in some cases, to estimate the braking power in time rather than in distance.

Now, theoretically, putting t = the time of braking, in seconds, then $t = \frac{e}{f}$. In practice this does not hold strictly true; hence $t = \frac{e}{f} - x$, where x is a constant to be derived from the experiments; $\therefore\ x = t + \frac{e}{f}$.

Now, from the Oldham experiments:—

For Fay's brakes	$x = 3, 6, 8, 8, 3, 8.$
For Newall's brakes	$x = 4, 2, 5, 0, 7, 8, 9.$
Hence mean	$x = 5 \cdot 4.$

$$\therefore\ t = \frac{e}{f} - 5 \cdot 4 = \left(\frac{e}{f_1} \times \frac{W}{w}\right) - 5 \cdot 4.$$

The above formulas will be found sufficient for the purpose of ascertaining the amount of brake-power required to arrest the motion of any train, within such a distance as may be considered safe by the railway company, or by the engineer; or in any given case, to determine the distance within which a train of any required weight may be stopped when travelling at any velocity.

Steam-Brakes.—During the last few years engineers have undertaken to construct railway brakes which would act more effectively than those previously used. Every engineer knows the imperfections of the apparatus and of plans for effecting the retardation or stopping of trains. He knows further how urgent the demand for such means is; the more so as it is desirable to take away from the tender as much weight as possible, and strengthen and lighten the engine by an extended application of steel, so that the tender may carry more fuel and feed-water, without increasing the total weight of the engine and loaded tender, or diminishing the power of the engine. Independently of these considerations, it is generally acknowledged that the retarding power ought to proceed from the same parts of the mechanism which transfers the propelling power, and that a properly constructed brake ought to be operated by the accumulated force when not required to propel the train. With those considerations in view, numerous experiments were made, and plans tried; however, applicable and satisfactory results were not obtained.

A correct investigation will show the error of providing for the carriages or wagons a separate brake-mechanism, even should the power to operate such mechanism be taken from the locomotive boiler. With locomotives, however, means must be found which will not only allow us to accumulate a sufficient retarding force in the boiler, but which will also give us the power to regulate its application and intensity, so as to destroy, gradually, the work conserved in the train and due to the weight of the train and its uniform velocity. At the same time the means provided must have the power to diminish by degrees, and ultimately to reverse, the tractive power of the engine.

We propose to examine the four following systems of steam-brakes, namely:—

1. The reversing of the valve-gear (System Lechatelier-Ricour).
2. The compression of the steam (System Zeh).
3. The compression of the air in the cylinder (System de Bergues).
4. The repression of the steam (Frein à Vapeur de Landsee, and Steam-repression Brake of Krauss and Co.).

The steam-brake of Krauss and Co. was designed by Professor Linde, of Munich.

The systems 1 and 4 depend upon the same principle, that is, the counter-effect of the steam; but the methods of application are different.

The Reversing of the Valve-gear.—The motion of any locomotive can be diminished by simply reversing the valve-gear; but it is easy to understand that the counter-effect of the steam increases quickly the pressure of the steam in the boiler. This is, however, a minor reason why the counter-effect of the steam should be applied, to suddenly stop trains, only in exceptional cases; for another disadvantage of a more serious character is to be met with. The exhaust-port opens in locomotives, not directly into the open air, but communicates, through the exhaust-pipe, with the interior of the smoke-box. Whilst the cylinders are now drawing in the air, they will thus not be filled with pure air, but with the gases of combustion from the smoke-box, which have not only a very high temperature of 400°, 500°, and upwards, but which also carry with them a great many unconsumed parts of the fuel. The disadvantageous influence which the practice of using the counter-pressure of the steam will have upon the engine and boiler of a locomotive will thus be at once understood. But let us examine the distribution of the steam produced by the reversing of the valve-motion, and we shall find that it is very disadvantageous, and becomes still more disadvantageous the faster the engines work and the more powerful the effect becomes.

Suppose the crank to stand at one of the dead points A, Fig. 1248, that it travels in the direction indicated by the arrow, and thus contrary to the valve-motion; then the angle of advance becomes negative. The steam enters the cylinder behind the piston, until the latter has reached the point B, where, at the ordinary working of the engine, the steam in front of the piston began to be admitted. It is a very short distance, but the clearances of the pistons are filled, and a small but accelerated expansion of the steam takes place till the piston reaches the point C. The compression began formerly at that point, but now a communication with the exhaust is effected, which remains open and allows the air to enter the cylinder behind the piston during the full forward stroke. This communication with the exhaust-pipe continues in front of the piston to the point D, where formerly the release of the steam began; an insignificant compression of the air follows next, till the piston arrives at E, where formerly the expansion of the steam began. But only now, after the piston has travelled a part of its stroke and its velocity becomes great in proportion to the velocity of the crank, the admission of the counter-effect begins through the slowly-opening

port: the piston has to travel a farther distance, dependent upon its velocity, before it meets in front with steam of sufficient pressure. The most important period has almost passed inefficaciously, and the work done by the piston is thus very insignificant. That work is represented in a graphical manner in Fig. 1248, by the dark hatchings *a b c d*, after the accelerated expansion work *c d e* has been deducted.

1251. 1249. 1250. 1248.

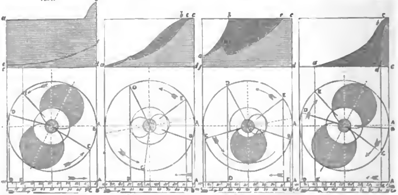


Diagram for the *steam-repression* brake. Diagram for the compression of the steam. *System Zeh.* Diagram for Landsee's steam-brake. Diagram for reversing the valve-gear.

Fig. 1248.—*e e*, Pressure of the steam in the boiler. E, Beginning of the admission of the counter-steam in front of the piston. D, Exhaust shut before the piston. B, The admission of steam cut off behind the piston. C, Exhaust opens behind the piston.

Fig. 1249.—D, Exhaust opens behind the piston. E, Expansion begins behind the piston. B, Admission of the steam begins in front of the piston. C, Exhaust shut before the piston.

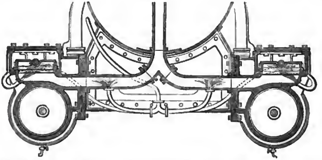
Fig. 1250.—D, Exhaust opens behind the piston. E, Expansion begins behind the piston. B, Communication with the steam-chest begins in front of the piston. C, The admission of the counter-steam begins in front of the piston.

Fig. 1251.—B, Communication with the steam-chest begins in front of the piston. C, Compression begins in front of the piston. D, Admission of the counter-steam begins behind the piston. E, Communication with the steam-chest shut behind the piston.

Engineers have always had sufficient reason to regret that drivers should be prohibited to apply this simple and powerful means of stopping trains: and, moreover, retardation by means of friction-brakes, considered theoretically as well as practically, is imperfect, since the *vis viva* of the trains had to be entirely destroyed by an external application of the brake, to diminish the velocity.

It is not surprising, under such circumstances, that the proposition of Lechatelier was soon approved of and applied first in France and then in Switzerland. According to M. Lechatelier's plan, Figs. 1252, 1253, a pipe is led from the exhaust-pipe of the engine to a small closed vessel,

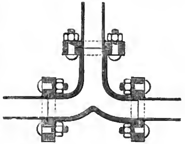
1252.



which is connected with the boiler by two other pipes, each furnished with a cock. One of these communicates with the boiler above, and the other below the water line, and by means of them

a mixture of steam and water can be introduced into the closed vessel, and from it, led by the pipe first mentioned, to the exhaust-pipe. The action of this arrangement is as follows:—When the engine is reversed for the purpose of retarding the train, the pistons would, under ordinary circumstances, pump air into the boiler, mixed with dust from the smoke-box, cutting and damaging the working surfaces of the cylinders and valves.

1253.



To prevent this damage, M. Lechatelier's plan provides for the admission of the mixture of steam and water into the blast-pipe when the engine is reversed, and the pistons then pump this mixture, instead of air, into the boiler. The water serves to lubricate the pistons, and the quantity admitted is just about as much as will be evaporated by the heat generated by the friction of the working parts. The supply of steam to the blast-pipe is generally allowed to be somewhat in excess of the quantity which can be pumped back into the boiler by the pistons, and the small quantity, which is thus constantly escaping at the blast-nozzle, serves to prevent the admission of a current of air. But experience has not only shown that Lechatelier's method, especially at a high speed of the engine, is in many cases not powerful enough, but that the admission of the proper quantity of steam and water requires great skill from the drivers.

The Compression of the Steam.—The method proposed by Zeh takes place by shutting the exhaust-pipe and placing the valve-gear on a high grade of expansion, so that the steam has to perform not only little work, but the escape of the expanded steam is also prevented, and the latter is thus compressed at the backward stroke of the piston.

The diagram, Fig. 1249, shows that the intensity of the effect can only be increased to a trifling degree. The pressure of the steam in front of the piston and at the commencement of the stroke can only be little more than that of the atmosphere, and the piston has to travel half of its stroke before the compression at C begins. When the crank arrives at B, almost at the end of the stroke, the pressure of the steam in front of the piston is still much less than the pressure of the steam in the boiler which acts now upon the piston for the remainder of the stroke. We get thus at first a retarding work, represented in the figure by the area $a\ b\ e\ c\ d$; next a propelling work, represented by the area $a\ e\ c\ d$, and composed of the area $c\ e$, the work done by the full pressure of the steam, and the area $e\ a$, the work done by the expansion of the steam. The comparison between the two works shows in fact a very insignificant effect of this method.

The Compression of Air in the Cylinders has been proposed by M. de Bergues as a means for retarding the motion of locomotives. According to M. de Bergues' plan, the regulator and the blast-pipe are shut, the admission-pipe is put in communication with an air-vessel which is provided with a safety-valve, the exhaust-pipe is put in communication with the atmosphere, and the valve-motion is reversed. The counter-pressure can thus be increased to a certain degree, independently of the pressure in the boiler; but here also the disadvantages appear to be very great. In the first instance, M. de Bergues sacrifices the relation to the boiler; and hence he cannot accumulate a sufficient retarding force. Next, he reverses the valve-motion, and has thus from the beginning a disadvantageous distribution of steam, which, moreover, must produce a limited effect of the power, as the pressure of the steam is very variable.

The air-vessel must not be too large, in order to produce, quickly, highly compressed air; a perceptible reduction of the pressure of the compressed air effects the filling of the steam-cylinders. The compression produces, besides, a high temperature in the cylinders, which require special precautions and a very abundant oiling; finally, the arrangement and management of the apparatus are rather complicated. It gives very good results for short runs, but not under prolonged working.

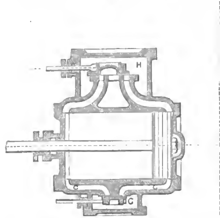
Steam-Brake of M. de Landsee.—M. de Landsee acts upon the very correct principle to produce the retarding power by means of using steam from the boiler as a back-pressure upon the pistons in a more advantageous manner than with the reversing of the valve-gear. For that purpose, M. de Landsee adds to the engine for the admission of the steam in front of the piston a second valve-gear, to the cylinder another steam-chest and another system of ports; for the movement of the second valve he fixes an eccentric rectangular to the crank, a link and the necessary gear. In order to retard the motion of the engine, the exhaust-pipe is shut, the main valve-gear is placed on a high grade of expansion, so that the steam behind the piston performs a little work by expansion, whilst the steam in front of the piston, which has entered the cylinder through the second steam-chest G, Figs. 1254, 1255, is pressed back into the boiler, and acts thus by its *repression* upon the piston in comparison to the compression performed in the cylinder.

It must be admitted that this arrangement offers a satisfactory solution of the existing problem; but if the apparatus is destined to produce a more powerful effect than the apparatus previously examined, two moments of some importance have been neglected.

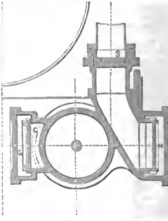
Let us examine what occurs during one revolution of the crank. The main valve H is supposed to have opened the port as much as the linear advance. The clearance of the piston, which in the present construction is enlarged on account of the second port communicating with the steam-chest G, amounting at least to $7\frac{1}{2}$ per cent. of the volume of the cylinder, is still filled with steam from the last repression. If we suppose $\frac{1}{16}$ to be the degree of expansion, or $17\frac{1}{2}$ per cent. the filling of the cylinders, $c\ e$ will show in a graphical manner, in Fig. 1250, the

work done under the full pressure of the steam, and e D the work performed during the expansion of the steam, where D represents the beginning of the release of the steam, which takes place

1254.



1255



after the piston has travelled about 70 per cent. of the stroke; the steam will thus have lost in a proportion of 77·5 to 17·5 of its pressure. Although the exhaust is shut and prevents the escape of this steam of almost ⅘ of the pressure of the steam in the boiler, a considerable volume of fresh steam enters the cylinder from that part of the exhaust which extends to the distribution-valve S, and which had been filled during the preceding repression. If we suppose the volume of that part to be 20 per cent. of that of the cylinder, the pressure of the steam will increase in a proportion of

$$\frac{17\cdot5}{77\cdot5} : \frac{17\cdot5}{77\cdot5} + \left(1 - \frac{17\cdot5}{77\cdot5}\right)\frac{20}{97\cdot5}, \text{ or } \frac{17\cdot5}{77\cdot5} : \frac{17\cdot5}{77\cdot5} + 0\cdot16.$$

At the end of the stroke the pressure will have again decreased in a proportion of 127·5 : 97·5, and we get thus with a pressure of 8 atmospheres in the boiler, after all, only a pressure of

$$p = 8\left(\frac{17\cdot5}{97\cdot5} + 0\cdot16\right)\frac{97\cdot5}{127\cdot5} = 2\cdot3 \text{ atmospheres.}$$

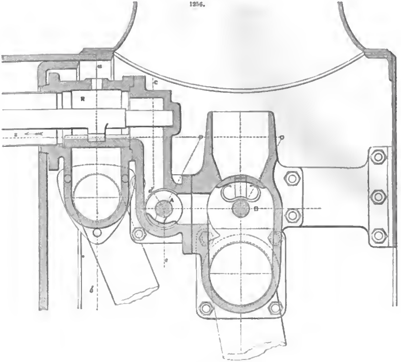
The value of the accelerated work is thus higher than at first calculated; it amounts at least to 45 per cent. of the total work performed by the piston (according to Boyle's law). But another circumstance, which reduces the retarding power at a high speed of the locomotive, has been entirely neglected, namely, the want of lead for the admission of the counter-steam. Of course, this lead could only be obtained on account of a still more disadvantageous distribution of the steam on the backward stroke of the piston, or by fixing a fourth eccentric. The valve G must thus travel a distance corresponding to its lap, before it admits the counter-steam into the cylinder, after the piston has reached the end of the stroke. At a high speed, the piston will have to travel a considerable part of its stroke before it meets in front with steam, the pressure of which is equal to that in the boiler.

The whole construction, although very ingenious, is too complicated, and the large clearances of the pistons, required by the two systems of ports, are great disadvantages. The simple principle, to admit steam into the cylinder, and to have it pressed back into the boiler by the movement of the piston, without any modification of the valve-motion, but by allowing the steam to enter the cylinders through the exhaust-pipes, instead of through the ordinary steam-pipes, has been adopted in

The Repression Brake of Krauss and Co., Munich.—This plan consists in an arrangement by means of which the steam can be made to enter the cylinders through the exhaust-pipes, instead of through the ordinary steam-pipes, the blast-nozzle being at the same time closed, and the steam admitted through the exhaust-pipes being pumped back, partly into the boiler, and partly into the steam-chests, from which it escapes through an adjustable valve into the chimney. Of course, the engine has not to be reversed, as in M. Lechatelier's arrangement.

The simplest arrangement is to place the regulator in the smoke-box, and to provide it with a segment-valve, as shown in Figs. 1256 to 1259. The regulator-valve R is connected with the blast-pipe by a tube A, and the blast-pipe is also provided with a segment-valve B. When the inlet to the steam-chest is shut by the first-mentioned valve, and the communication with the blast-pipe is open, the outlet of the latter being shut, then the steam passes from the boiler, through the tube and the blast-pipe, into the outlets or discharged ports of the slide-valve, and rushes against the piston with a counter-pressure equal to the steam-pressure during nearly the full stroke, that is to say, during the time that the steam is acting to work the engine; during this counter-pressure the steam is returned into the boiler. When about $\frac{9}{10}$ of the stroke has been

1256.



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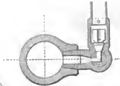

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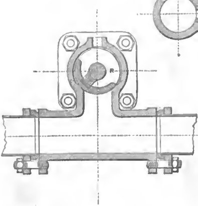
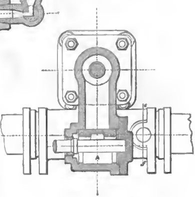
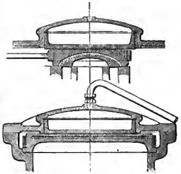


1258.



accomplished, the outlet is shut, and the steam being still in the cylinder, is further compressed till the ordinary inlet is opened by the slide-valve; and this steam can then escape to the steam-chest, and from there through a valve to the chimney. This valve is regulated by a cock, and can be put in communication through the inlet-tube, Fig. 1261, with the steam-chest, but during the working of the engine the valve is shut. This valve regulates the quantity of steam which is retained in the steam-chest, and also regulates the work of the brake. The regulation of the back-pressure may also be effected by regulating the steam-pressure in the blast-pipe, and this is done by enlarging or narrowing the inlet opening, also by admitting steam to the steam-chest through the regulator-valve and expansion-valve; that is to say, by the introduction of steam into the cylinder on both sides of the piston. To simplify the working of the apparatus, the regulator-valve, the blast-pipe valve, and the valve with the regulating cock, are connected by levers, so that by simply moving the regulator the engine can be driven at full speed, or can be reversed. By this arrangement of the apparatus it is possible nearly instantaneously to change the propelling force of the engine into a retarding force. When the piston is nearly at the end of the stroke, on the other side, the slide-valve begins to open the admission openings, and the steam passes into the empty cylinder, so that the latter is full of steam when the piston returns; this steam is now forced back into the boiler. This action continues till the slide-valve shuts the communication between the cylinder and the admission opening; the confined steam is then further compressed. This compression is at the highest point when the slide-valve is in communication with the cylinder and the steam-chest just before the crank is at the dead point; the steam then passes into the steam-chest and through the valve. It is necessary that the slide-valves should be prevented from being pressed back by the compressed steam, and Figs. 1257 to 1261 show the arrangement employed for that purpose. The valve, it will be seen, is fitted with a piston, at the back of which is a hole, which is connected by a tube with the blast-pipe, so that while braking, the steam can act upon the piston and prevent the pressing back of the slide-valve. Fig. 1251 shows the distribution and action of the steam in a graphical manner. At D, where formerly the release of the steam began, the admission of the counter-steam into the cylinder commences, so that when the piston arrives at the end of its stroke, the whole cylinder is filled with counter-steam, which has to be pressed back into the boiler by the piston, till the crank has reached the point C, when the communication with the blast-pipe is cut off. The remaining steam is compressed until the point B is reached, when it escapes through the valve into the steam-chest. Whilst the steam acts with full pressure during the whole stroke *in front* of the piston, the communication with the steam-chest is maintained *behind* the piston, until the crank arrives at the point E.

1260.

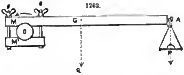


1261.

Dynamometer-Brake.—Prony's Friction Dynamometer-Brake.—A friction brake may be employed to measure the power applied to, and the mechanical effect produced by, a shaft or other part of a machine which revolves uniformly; it must be clearly understood that neither the power nor the effect can be measured unless the revolutions continue uniform after the brake is applied and adjusted. Piobert and Fardy, in 1821, applied a brake as a dynamometer to determine the power of water-wheels; but M. Prony first applied a brake to determine the power transmitted by steam.

It was determined by experiment that friction had a uniform resisting power that might be intensified by pressure: Prony contrived a brake to apply this retarding power to bring revolving shafts to given or required uniform velocities, so that the power applied by, or conserved in, a machine might be measured. Prony's brake, in its simplest form, is shown in Fig. 1262. Let the circle O be a cross-section of a horizontal shaft, which is revolving, but not uniformly; M, M, A, is the brake, the pressure of which may be increased or diminished by tightening or loosening the screws e, e, respectively. A circular cavity is made in the two wooden jaws M, M', which receives the revolving shaft O; the upper jaw M is lengthened to support a balance scale A P, which may be loaded with any required weight. The operation which we are about to describe must not be confounded with that of weighing a body by means of a lever and fixed prop. Now, suppose that a shaft O makes k uniform revolutions a minute, and, at the same time, drives any machinery whatever, and that we require to know the amount of power employed in driving such machinery. To effect this object, the communication between the shaft O and the machinery driven by it must be removed, and the brake so tightened on the shaft that it will make just k revolutions a minute. While the brake is being pressed by the screws e, e, to obtain the necessary amount of friction, it is prevented from being turned with the shaft by props. Then weights are placed in the scale A, to bring the arm M A into a horizontal position: the props which prevented the brake from being

1262.



whirled round with the shaft are not in contact with the brake when M A is horizontal. When the brake is thus screwed up and poised, the shaft must continue to make k uniform revolutions a minute; then the power transmitted by the shaft O may be calculated. Let P be the weight suspended at A, and p the perpendicular distance from the centre of O to the line A P; Q the weight of the scale and that part of the apparatus which assists the weight P; G its centre of gravity, and q the perpendicular distance from O to the line G Q. The reaction of the friction of the jaws M, M', upon the revolving shaft O may be resolved into normal forces $n, n', n'', \ldots$ and tangential forces $f, f', f'', \ldots$ acting in the direction of the rotatory motion. When the equilibrium of the apparatus is established, the sum of the moments of these different forces, in relation to the centre of O, must be equal to zero. But the normal forces have no moments, and if r be put for the radius of the shaft, we have the equation $f r + f' r + f'' r + \ldots - P p - Q q = O$. Or putting $\Sigma f r$ for the sum of the forces $f r + f' r + f'' r + \ldots$ we have the equation

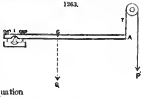
$$\Sigma f r = P p + Q q. \qquad [1]$$

Taking the angular velocity at the distance of a unit from the centre of O (see ANGULAR VELOCITY), the work of friction for one revolution is found by multiplying $\Sigma f r$ by 2π, π being put $= 3 \cdot 14159 \ldots$; whence, if N = the number of revolutions a minute, and if $\mathcal{Q}_f$ be put for the work of the friction in a second, we have $\mathcal{Q}_f = \frac{2 \pi N}{60} \Sigma f r$. When the value of the general expression conventionally written $\Sigma f r$, from equation [1], is substituted, we have

$$\mathcal{Q}_f = \frac{\pi N}{30} (P p + Q q). \qquad [2]$$

The weight P, required to bring A M to a horizontal position, and the perpendicular distance p, are known. The moment $Q q$ may be found in the following manner:—The apparatus is weighed, as shown in Fig. 1263, by supporting the brake, detached, on a knife-edge I, and bringing the lever I A into a horizontal position by means of a weight P' attached to a cord, which passes over a fixed pulley, and is connected to the end A of the lever. The friction of the pulley being neglected, the tension T is equal to the force P', and we have the equation

1263.



$$T p = Q q \text{ or } P' p = Q q. \qquad [3]$$

The weight P' is termed the permanent load.

Substituting $P' p$ for $Q q$ in equation [2], we obtain the equation

$$\mathcal{Q}_f = \frac{\pi N}{30} (P + P') p. \qquad [4]$$

N the uniform revolutions and P become known when the brake is perfectly adjusted.

If, for example, $p = 2^m \cdot 50$; $P' = 30^k$, and the shaft O, Fig. 1262, to make continually forty uniform revolutions a minute when $P = 120^k$, then $N = 40$, and the general expression

$$\mathcal{Q}_f = \frac{3 \cdot 14159265 \times 40}{30} (120 + 30) \times (2 \cdot 5) = 1570 \cdot 79633$$

French units of work, or 1570·79633 kilogrammes raised the height of 1 mètre. The French consider a horse-power = 75 kilogrammes raised 1 mètre in a second. 75 French units of work are equal to 542·5 English units of work; $\frac{33000}{60} = 550$; but $550 : 542 \cdot 5 :: 1 : \cdot 9864$; therefore an English horse-power is a French horse-power, as 1 is to ·9864 nearly. $1570 \cdot 79633 \div 75 = 20 \cdot 94$ horse-power, according to the French method of measurement.

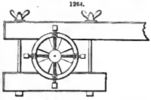
Again, suppose $p = 8$ ft.; $P' = 50$ lbs.; $P = 250$ lbs.; and $N = 40$; then

$$\mathcal{Q}_f = \frac{3 \cdot 1416 \times 40}{30} (250 + 50)\, 8 = 10052 \cdot 12 \text{ units of work a minute;}$$

$$\therefore \quad \frac{10052 \cdot 12}{550} = 18 \cdot 28 \text{ horse-power (English).}$$

In practice, the jaws are not directly applied to the shaft; but if the latter is of cast iron, a circular frame, expressly framed and bored for that purpose, is fastened to it by means of adjusting-screws. If the shaft is of timber, and of a large size, it is surrounded by a ring formed of two parts and provided with screws for its correct centering; this ring is fastened to the shaft by means of wedges. In both cases the jaws of the brake are applied to the circular frame or ring, as shown in Fig. 1264.

1264.



If the product $\Sigma f r$ or $r \Sigma f$ remains the same for an equal number of horse-power, Σf is so much greater, the smaller r is taken. But the friction may thus become too great, and by altering, consequently, the contacting surfaces, it will also lose its uniformity. Experience has proved that with

a diameter of between	and a velocity of between	the power can be measured of
16 and 20 centimètres,	20 and 30 revolutions per minute,	6 or 8 horses,
30 „ 40 „	15 „ 30 „ „	15 „ 25 „
60 „ 80 „	15 „ 30 „ „	40 „ 70 „

A high speed is, besides, favourable to the regularity of the experiment, as M. Morin has confirmed at Bonchet. A uniform friction is necessary for the maintenance of the equilibrium of the lever during the rotatory motion of the shaft; the lever assumes always a little oscillating motion, which is of no consequence as long as it keeps within strict limits; but if these oscillations become considerable, an irregularity in the friction has taken place, and the retarding power of the friction cannot under such circumstances be measured.

On account of the length of the lever, the weight at A, Fig. 1262, may of itself tighten the screws; in order to remove this inconvenience, which sometimes produces false results, M. Poncelet has proposed to make the two jaws of equal length, and to place the bolts near the point A, Fig. 1265. The flexibility of the wood permits a gradual tightening, which renders this arrangement preferable to the ordinary one.

1265.

A little more than half the brake is shown in this figure.

To establish stable equilibrium, M. Poncelet applied the weight, not to the point A itself, but to the end of a vertical rod A B, fastened to one of the jaws. It thus happens, that if the lever begins to turn round with the shaft, the lever-arm of the weight P increases immediately, and the friction ceasing to be preponderant, the apparatus returns to its equilibrium.

If the shaft is vertical, the weight cannot be applied directly to the end of the lever, but a cord fastened to it is made to pass horizontally in a perpendicular direction over a fixed pulley.

A plummet suspended before the end of the lever will show the position of the brake when equilibrium is established.

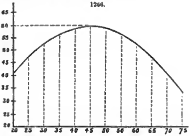
M. Morin has extended the useful application of the brake as a dynamometer, for he does more than measure by it the work done for a given or required uniform velocity of a shaft.

The extended application to which we allude may be thus described:—

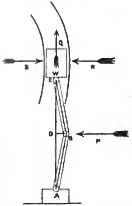
When the shaft turns round without meeting with any resistance, and after the supports of the lever have been removed, a weight between 5 and 10 kilogrammes is placed at the end of the lever; the screws are now tightened, till an equilibrium of the apparatus is established. The uniform velocity or speed of the shaft is measured, and the units of work done are ascertained. A new weight is again added to that already acting at the end of the lever; the screws are made more tight, until equilibrium is again established, and the uniform speed of the shaft and the work performed are determined. The weight at the end of the lever is gradually increased, and the screws for the establishment of an equilibrium tightened, till the shaft stops or turns in an irregular manner. The work done, in each second, is thus obtained for a variety of uniform speeds, from the greatest to the least possible. A curve is drawn, the abscissæ of which represent the velocities, and the co-ordinates the corresponding values of the ratios between the work given by the brake and the work of the motor. This curve indicates the nature and power of the machine; it gives the performed work corresponding to an average uniform speed of a shaft, and, besides, it shows the uniform speed which corresponds to the maximum effect.

Fig. 1266 represents the results of a series of experiments made with a turbine of the System Fontaine. The abscissæ are proportional to the number of revolutions of the wheel a minute, and the co-ordinates represent the corresponding values of the actual effects multiplied by 100. It will be seen from the diagram that the maximum actual effect is produced with about forty-five uniform revolutions, and that this maximum is about 0·60, that is to say, the maximum actual effect is 0·60 of the motive power.

1266.



1267.



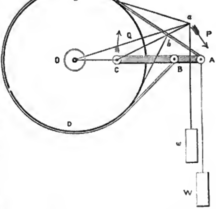
Writers on mechanics, and especially those who attempt to explain the action of a brake employed as a regulator to produce a uniform effect, do not draw a proper distinction between the action of a toggle, and that of a system of compound levers. To place this matter in a clear light we have only to explain the action of a simple toggle-joint, since the properties of the lever are well known.

Let A B = B C = 144·01 in. be the arms of a toggle-joint, Fig 1267; the point A is fixed, but the rod A B may be turned round A as a centre. The joints B and C are also loose, but C is constrained to move in a given path. In the right-angled triangle D C B = D A B and D B perpendicular to A C; putting D B = 2·4 in., then C D = D A = 143·99 in.

Suppose a force P of 200 lbs. to be applied at B, in the direction of B D as indicated by the arrow P; when the two bars A B, B C, are brought into a straight line in the direction of the arrow Q, what weight W may be thus moved by the action of the force P? W is constrained to move in a given path by the action of the equal forces R and S. Units of work done by $P = \frac{2\cdot 4}{12} \times 200 = 40$ units of work. $287\cdot 98 = A\,C$, and $A\,B + B\,C = 288\cdot 02$. $288\cdot 02 - 287\cdot 98 = \cdot 04$ in., the space over which W must pass in the direction indicated by the arrow Q when B is moved from B to D. $\therefore\ \frac{\cdot 04}{12}$ W = the units of work done in raising W, consequently $\frac{\cdot 04}{12}\,W = 40$, or $\frac{W}{300} = 40$; $\therefore$ W = 12000 lbs., which exceeds 5 tons.

John George Appold's brake, which constituted the most important part of the machinery employed to pay-out the French Atlantic Cable, owes its efficiency and success to a judicious application of the toggle-principle to control and regulate the retarding power of friction. The principle upon which Appold formed this mechanical combination may be thus explained:— In Fig. 1268, O is the pivot of the brake-wheel, C the pivot on which the lever C, A, B, works; W represents the weight on the brake. The brake-wheel D E is attached to the paying-out drum. When the friction of the brake-strap B D E A is greater than the weight W, the latter is lifted up and takes a position w; C B A takes the position C b a; the strap takes the position b D E a; and the force W may be resolved into two forces, one acting along a b c, which is neutralized by the pivot C, and another P acting perpendicular to C a; the reacting force Q on the pivot C straightens the toggle O C a into its original position O C B A, by a very trifling force Q. Thus the strap a E D b is relaxed and allows the wheel D E to slip.

1268.



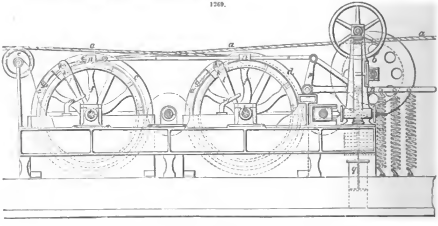
J. G. Appold's Brake Apparatus for Laying Submarine Telegraphic Cables, Figs. 1269, 1270, relates to a novel arrangement or construction of a self-acting or self-relieving brake, which may be adapted to the drums, pulleys, or shafts of the apparatus employed for submerging or paying-out telegraphic cables into the water. It is advisable that the strain on the cable while being payed-out into the water should be always maintained as uniform as possible under all circumstances, so that no danger of breaking or damaging the cable by any sudden or undue strain may be apprehended. This object is effected by adapting to the shafts of the paying-out pulleys a drum, on the surface of which a uniform friction is maintained by means of binding bands or straps, which are connected with a weighted vibrating or movable lever. This lever is capable of being weighted to any desired extent, according to the amount of friction required to be maintained. The weights or pressure put on the brake determines the friction thereof on the rotating drums, and consequently the amount of strain on the cable, which strain can be regulated with nicety and great facility. The weights or pressure acting on the vibrating lever or other convenient part of the brake has a tendency to draw the friction strap or band tight on the rotating drum, while the rotation of the drum has a constant tendency to lift the weight, and, by loosening the strap or band on the drum, to relieve the brake from the pressure to which it is subjected. From this it will be understood that these two forces are acting in opposition, and consequently the one has a tendency to counteract the other, so that a uniform strain or friction is always maintained on the rotating drum, the amount of the friction being regulated by the amount of the pressure or weight adapted to the drum.

It will now be understood that the brake is perfectly self-acting, and the friction thereof is always maintained uniform. Provision may be made for relieving the brake from pressure instantaneously when required by means of suitable gearing, whereby the weighted lever or levers is or are lifted up, and the friction straps or bands thereby loosened on the rotating drums. This may be effected by means of a hand-wheel, or by connecting the gearing with a drum or shaft to be actuated by the engine which works the paying-out gear.

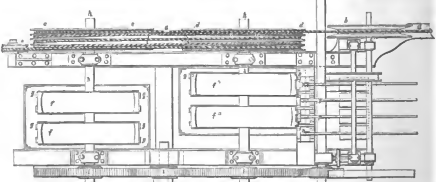
Fig. 1269 is a side elevation, and Fig. 1270 a plan view, of an apparatus for paying-out cables. The cable a enters the apparatus over a grooved guide-wheel or pulley b, from whence it passes to one of the grooves of a four-grooved drum or pulley c, and after passing round this drum or pulley it is conducted round a similar grooved drum or pulley d, and so on, the cable being made to pass four times round the two-grooved drums c and d, from which it is ultimately delivered over another pulley e, either directly into the water or through a dynamometer apparatus, whereby the tension or strain on the cable may be ascertained and indicated. On the axles or shafts h of each of the grooved drums c and d are two friction wheels or drums f, f, f^*, f^*, which

are surrounded by friction-bands g, g, g^*, g^*, provided with segmental blocks of wood, which when the bands are drawn tight are made to press on the surface of the wheels or drums f, f^*, and thereby produce the necessary amount of friction to act as a brake upon the drums. On the ends of the shafts h are mounted the toothed wheels i, i, Fig. 1270, which are geared together by the pinion i, and therefore rotate at the same speed. This toothed gearing, however, is not required while the cable is being lowered or submerged, and therefore it may be thrown out of gear during this operation, and will only be required when the apparatus is used to haul in the cable, as would be required in case of accident to the cable.

1269.



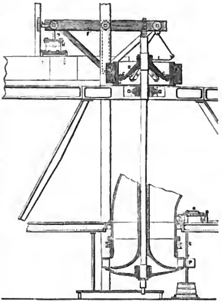
1270.



The ends of the straps or bands g, g^*, are secured in any convenient manner to pins k, k, Fig. 1269, fixed on the vibrating levers l', l', each of which passes through a hole made in the arms m. The holes in these arms form the centres of motion of the levers l', l', and as these centres of motion are on one side of the centre of the friction wheels f, f^*, and bands g, g^*, it follows that by causing these levers l', l', to move on their centres of motion, as indicated in Fig. 1269, they will either tighten or loosen the friction-bands, according to the direction in which the levers are moved. On the upper side of the bands are fixed the blocks n, n, to which are attached the horizontal rods o, o, which are secured at one end to one of the blocks n by an adjustable attachment, as shown in Figs. 1269, 1270, and they are jointed at their opposite ends to the vibrating bell-crank levers p, p. These levers are supported in bearings fixed on the framing, and to the longer end of each is adapted a weight or weights, or a system of springs or other contrivances, whereby the levers may be depressed; and by the levers thus drawing forward the horizontal rods o, o, they will tend to tighten the friction-bands g, g^*, round the friction-drums f, f^*. It will now be understood that as the cable is being payed-out, it (by passing round the grooved pulleys c and d) draws the friction-wheels f, f, round, and by the friction of the wheels f on the bands g^*, g^*, tends to open

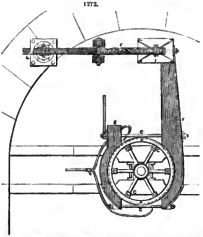
the latter, and thereby relieve the wheels from the friction of the bands. At the same time the weights or springs on the ends of the bell-crank levers p, p, will draw the friction straps or bands g, g^*, in the opposite direction, thereby having a tendency to tighten them on the friction-wheels f, f^*. These two forces will always be acting in contrary directions, and any increase in the action of the one will be counteracted by the other. In order to prevent any jar in the machinery by the weights at the end of the bell-crank levers p, p, suddenly descending when the friction on the bands or straps g, g^*, alters, it is convenient to attach to the weights, which are made of a cylindrical or other convenient form, a piston, which is made to work in a cylinder q. This cylinder or *dash-pot* is supplied with water, and as the piston is made pretty nearly to fit the internal diameter of the cylinder q, the water will to some extent moderate and regulate the motion of the weights, and will prevent them from jumping up and down. It is convenient to cause the friction-wheels to rotate or work in water, as shown at Fig. 1270, for the purpose of keeping them cool.

1271.



When a dynamometer apparatus is employed in conjunction with the paying-out apparatus, for the purpose of indicating the changes that take place from time to time in the tension of the cable, Appold employs an apparatus constructed upon an improved plan, whereby weights are dispensed with, and springs employed in place thereof. The cable when delivered from the paying-out apparatus above described, passes from the delivery pulley under or over a movable pulley, which is mounted on a block that works up and down in vertical guides. This block is supported at a given altitude in the guides by means of coiled or other springs placed either above or below the pulley, which is made to bear against the cable, and as the tension thereof varies, so the pulley with its block is caused to rise or fall in its guides, as is well understood in reference to ordinary dynamometers. This invention shows that John George Appold was a man of considerable genius and profound mechanical skill.

1272.



The Prony dynamometer-*brake* employed by J. B. Francis in making experiments on hydraulic motors is shown in Figs. 1271, 1272; Fig. 1271 is a sectional elevation, and Fig. 1272 is a sectional plan. The friction-pulley A is of cast iron, 5·5 ft. in diameter, 2 ft. wide on the face, and 3 in. thick. It is attached to the vertical shaft by the *spider* B, the *hub* of which occupies the place on the shaft intended for the bevel-gear. The friction-pulley has on its interior circumference six *lugs* C, C, corresponding to the six arms of the spider. The bolt-holes in the ends of the arms are slightly elongated in the direction of the radius, for the purpose of allowing the friction-pulley to expand a little as it becomes heated, without throwing much strain upon the spider. When the *spider* and friction-pulley are at the same temperature, the ends of the arms are in contact with the friction-pulley. The friction-pulley was made of great thickness for two reasons. When the pulley is heated, the arms cease to be in contact with the interior circumference of the pulley, consequently they would not prevent the pressure of the brake from altering the form of the pulley. This renders great stiffness necessary in the pulley itself. Again, it was found that a heavy friction-pulley

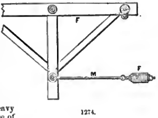
increases more regularity in the motion, operating, in fact, as a fly-wheel, in equalizing small irregularities.

The *brakes* E and F are of maple wood; the two parts are drawn together by the wrought-iron bolts G G, which are 2 in. square.

The *bell-crank* F' carries at one end the scale I, and at the other the piston of the *hydraulic* REGULATOR K; this end carries also the pointer L, which indicates the level of the horizontal arm. The vertical arm is connected with the brake F by the link M, Fig. 1273.

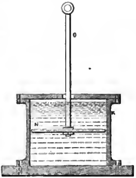
The *hydraulic regulator* K, Figs. 1271, 1272, and 1274, is a very important addition to the Prony dynamometer-brake, first suggested by Boyden in 1844. Its office is to control and modify the violent shocks and irregularities which usually occur in the action of this valuable instrument, and are the cause of some uncertainty in its indications.

1273.



The hydraulic regulator used in these experiments consisted of the cast-iron cylinder K, about 1·5 ft. in diameter, with a bottom of plank, which was strongly bolted to the capping-stone of the wheel-pit, as represented in Fig. 1271. In this cylinder moves the piston N, formed of plate iron 0·5 in. thick, which is connected with the horizontal arm of the bell-crank by the piston-rod O. The circumference of the piston is rounded off, and its diameter is about $\frac{1}{16}$ in. less than the diameter of the interior of the cylinder. The action of the hydraulic regulator is as follows:—The cylinder should be nearly filled with water, or other heavy inelastic fluid. In case of any irregularity in the force of the wheel, or in the friction of the brake, the tendency will be either to raise or lower the weight; in either case the weight cannot move, except with a corresponding movement of the piston. In consequence of the inelasticity of the fluid, the piston can move only by the displacement of a portion of the fluid, which must evidently pass between the edge of the piston and the cylinder; and the area of this space being very small, compared to the area of the piston, the motion of the latter must be slow; giving time to alter the tension of the brake-screws before the piston has moved far. It is plain that this arrangement must arrest all violent shocks; but, however violent and irregular they may be, it is evident that, if the mean force of them is greater in one direction than in the other, the piston must move in the direction of the preponderating force, the resistance to a slow movement being very slight. A small portion of the useful effect of the turbine must be expended in this instrument; probably less, however, than in the rude shocks the brake would be subject to without its use.

1274.



For the purpose of ascertaining the velocity of the wheel, a counter was attached to the top of the vertical shaft, so arranged that a bell was struck at the end of every fifty revolutions of the wheel.

To lubricate the friction-pulley, and at the same time to keep it cool, water was let on to its surface in four jets, two of which are shown in Fig. 1272. These jets were supplied from a large cistern, in the attic of the neighbouring building, kept full by force-pumps. The quantity of water discharged by the four jets was, by a mean of two trials, 0·0288 cubic ft. a second.

In many of the experiments with heavy weights, and consequently slow velocities, oil was used to lubricate the brake, the water, during the experiment, being shut off. It was found that, with a small quantity of oil, the friction between the brake and the pulley was much greater than when the usual quantity of water is applied; consequently, the requisite tension of the brake-screws was much less with the oil, as a lubricator, than with water. This may not be the whole cause of the phenomenon; but, whatever it may be, the ease of regulating in slow velocities is incomparably greater with oil, as a lubricator, than with water applied in a quantity sufficient to keep the pulley cool. The oil was allowed to flow on in two fine continuous streams; it did not, however, prevent the pulley from becoming heated sufficiently to decompose the oil, after running some time, which was distinctly indicated by the smoke and peculiar odour. When these indications became very apparent, the experiment was stopped, and water let on by the jets, until the pulley was cooled. As the pulley became heated, the brake-screws required to be gradually slackened.

In the experiments, in Table II. (see TURBINE WATER-WHEEL), the lubricating fluid was as follows:—

In the first twenty-six experiments, water alone was used.

In the four experiments numbered from 27 to 30, three gallons of linseed-oil were used.

In all the experiments requiring a lubricator, and numbered from 31 to 48, inclusive, linseed-oil was used.

In experiments 49 and 50, resin-oil was used.

In experiments numbered from 51 to 60, inclusive, water alone was used.

In experiment 61, resin-oil was used.

In experiment 62, resin-oil and a small stream of water were used:—in the latter part of the experiment, a good deal of steam was generated by the heat of the friction-pulley.

In experiment 63, resin-oil alone was used.

In experiments numbered from 66 to 72, inclusive, water alone was used.

In experiments numbered from 73 to 79, inclusive, resin-oil and a small stream of water were used.

In experiments numbered from 81 to 84, inclusive, water alone was used.

In experiments 85 and 86, resin-oil and a small stream of water were used.

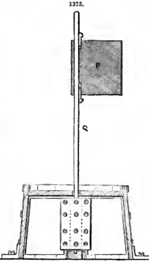
In experiment 87, resin-oil alone was used.

In experiments 90 and 91, water alone was used.

In experiment 92, resin-oil and a small stream of water were used.

A special apparatus was provided to indicate the direction in which the water left the wheel. For this purpose the vane P, Figs. 1271, 1275, 1276, was placed near the circumference of the wheel, and was keyed on to the vertical shaft Q, which turned freely on a step resting on the wheel-pit floor. The upper end of the shaft carried the hand R, Fig. 1271, and directly under the hand was placed the graduated semicircle S, divided into 180°. When the vane was parallel to a tangent to the circumference of the wheel, drawn through the point nearest to the axis of the vane, and the vane was in the direction of the motion of the wheel, the hand pointed at 0°, and, consequently, when the vane was in the direction of the radius of the wheel, the hand pointed at 90°. To prevent sudden vibrations of the vane, a modification of the *hydraulic regulator* was attached to the lower part of the vane-shaft. This apparatus is represented in detail by Figs. 1275, 1277.

1275.

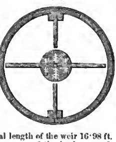


The quantity of water discharged by the wheel was gauged at a weir erected for the purpose at the mouth of the wheel-pit.

As the water issued from the orifices of the turbine with considerable force, particularly when the velocity of the wheel was much quicker or slower than that corresponding to the maximum coefficient of effect, there were often such violent commotions in the wheel-pit, that, unless some mode was adopted to diminish them before the water reached the weir, or even the place where the depths on the weir were measured, it would have been impossible to make a satisfactory gauge of the water. For this purpose a grating was placed across the wheel-pit. This grating presented numerous apertures, nearly uniformly distributed over its entire area, through which the water must pass. In the experiments with a full gate, the fall from the upper to the lower side of the grating was generally from 3 to 4 in. The combined effect of this fall and of the numerous small apertures was to obliterate almost entirely the whirls and commotions of the water above the grating. About 4·5 ft. in length of the grating was so nearly closed that but little water passed through that part of the grating; this made it very quiet in the vicinity of the gauge-box.

1276.

1277.



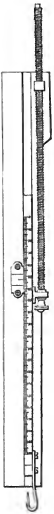
The weir consisted of two bays of nearly equal length; the crest of the weir was almost exactly horizontal, and the extreme variation did not exceed 0·01 in. The crest of the weir was of cast iron, planed on the upper edge, and also on the upstream face, to a point 1·125 in. below the top; below this there was a small bevel, also planed, the slope of which, on an average, was $\frac{1}{16}$ in. in a height of $\frac{5}{8}$ in.; the remainder of the casting was unplaned. The crest of the weir was $\frac{3}{8}$ in. thick, and was horizontal. The upstream edge was a sharp corner. The ends of the weir were of wood, and of the same form as the crest, except that there was no bevelled part. The crest of the weir was about 6·5 ft. above the floor of the wheel-pit. The ends of the weir projected from the walls of the wheel-pit, and also from the central pier, a mean distance of 1·235 ft. The length of one bay was 8·489 ft., and of the other 8·491 ft., making the total length of the weir 16·98 ft.

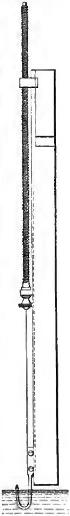
The depth of the water on the weir was taken in a gauge-box by means of the hook-gauge L, which is represented in detail in Figs. 1278 to 1280.

The hook-gauge is the invention of Boyden, and is an instrument of inestimable value in hydraulic experiments. In 'Versuche über den ausfluss des wassers durch schieber, hähne, klappen und ventile,' by Julius Weisbach, Leipzig, 1842, page 1, is described an instrument for observing heights of water, having a slight resemblance to the hook-gauge; it was, however, used by Boyden in a more perfect form several years previous to the publication of that work. All other known methods of measuring the heights of the surface of still water are seriously incommoded by the effects of capillary attraction; this instrument, on the contrary, owes its extraordinary precision to that phenomenon. The point of the hook A, Fig. 1279, is represented as

coinciding with the surface of the water. If the point of the hook should be a very little above the surface, the water in the immediate vicinity of the hook would, by capillary attraction, be elevated with it, causing a distortion in the reflection of the light from the surface of the water. The most convenient method of observing with this instrument is, first, to lower the point of the hook, by means of the screw, to a little distance below the surface; then to raise it again slowly, by the same means, until the distortion of the reflection begins to show itself; then to make a slight movement of the screw in the opposite direction, so as just to cause the distortion to disappear; the point will then be almost exactly at the level of the surface.

1278. 1279.





With no particular arrangements for directing light on the surface, differences in height of 0·001 ft. are very distinct quantities; but by special arrangements for light and vision, differences of 0·0001 ft. might be easily appreciated.

As this instrument cannot be efficiently used in a current, it was placed in a box in which the communication with the exterior was maintained by a hole, when, by partially obstructing this communication, the extent of the oscillations could be diminished at will.

For very exact observations it is essential that the surface of the water should be at rest. If, however, it should oscillate a little, a good mean may be obtained by adjusting the point of the hook to a height at which it will be visible above the surface of the water only half the time.

The movable rod to which the hook was attached was of copper, and graduated to hundredths of feet, but by means of the *vernier* thousandths were measured, and in some cases ten thousandths were estimated. In later and more perfect forms of this instrument, the point of the hook is immediately under the graduation.

The heights of the water in the fore-bay and in the wheel-pit were taken by means of gauges, placed in the gauge-boxes. Both gauges were graduated to feet and hundredths, and both had the same zero-point, namely, the level of the crest of the weir, so that the difference in the readings at the two gauges gave at once the fall acting upon the wheel; and the difference between the depths of the water on the weir, as observed at the hook-gauge, and the reading at the gauge, gave the fall at the grating.

The heights of the regulating-gate were taken at the rack. The weights used for measuring the useful effect were pieces of pig-iron of various sizes, each of which had been distinctly marked with its weight.

Mode of Conducting the Experiments.—A separate observer was appointed to note each class of data: the time of each observation was also noted, which gave the means of identifying simultaneous observations. To accomplish this, each observer was furnished with a watch having a second-hand; the watch by which the speed of the wheel was observed was taken as the standard; all the others were frequently compared with it, and when the variations exceeded ten or fifteen seconds they were either adjusted to the standard, or the difference noted.

This mode of observing must, evidently, lead to more precise results than that in which a single observer, however skilful, undertakes to note all the phenomena, or even several of them. By the method adopted a regular record is made of the state of things at very short intervals, furnishing the data for a mean result for any required period, and also the means of detecting, in most cases, the causes of apparent discrepancies. It also relieves the experimenter from the distraction of having numerous exact observations to make in a very short time, and leaves him much more at liberty to exercise a vigilant watch over the general course of the experiment.

1280.

As it may be useful to experimenters not accustomed to this mode of observing, and at the same time afford the reader some means of judging of the accuracy of the results obtained in these experiments, the following extracts are given from the original note-books. The extracts include the data observed for experiment numbered 30 in Table II. (see TURBINE WATER-WHEEL). This experiment is selected simply because it gave the maximum coefficient of effect.

Weight in the Scale.

	lbs.	oz.
	1498	10¼
4h 43' added	26	0½
Weight for the next experiment	1524	10¾

Speed of the Wheel.

Times at which the Bell struck.	Differences.	Times at which the Bell struck.	Differences.	Times at which the Bell struck.	Differences.
hrs. min. sec.	sec.	hrs. min. sec.	sec.	hrs. min. sec.	sec.
4 55 58·00		5 0 52·00	59·00	5 4 47·00	59·00
56 56·50	58·50	1 50·75	58·75	5 45·50	58·50
57 55·25	58·75	2 49·50	58·75	6 44·25	58·75
58 54·25	59·00	3 48·00	58·50	7 43·00	58·75
59 53·00	58·75				

The bell struck once in every fifty revolutions of the wheel.

Elevation of the Pointer on the Bell-Crank.

Time.	Height of Pointer, in Feet.	Time.	Height of Pointer, in Feet.	Time.	Height of Pointer, in Feet.
hrs. min. sec.		hrs. min. sec.		hrs. min. sec.	
4 55 0	0·19	4 59 30	0·20	5 4 0	0·17
30	0·13	5 0 0	0·18	30	0·18
56	0·13	30	0·19	5	0·24
30	0·14	1	0·21	30	0·18
57	0·15	30	0·17	6	0·19
30	0·19	2	0·20	30	0·19
58	0·20	30	0·19	7	0·16
30	0·19	3	0·19	30	0·14
59	0·21	30	0·19		

The extremity of the pointer was 6·5 ft. from the fulcrum of the bell-crank. When the horizontal arms of the bell-crank were level, tho height ef the pointer was 0·20 ft.

Height of the Water above the Wheel.

Time.	Height, in Feet.	Time.	Height, in Feet.	Time.	Height, in Feet.
hrs. min. sec.		hrs. min. sec.		hrs. min. sec.	
4 55 0	15·100	4 59 30	15·110	5 4 0	15·120
30	15·100	5 0	15·115	30	15·120
56	15·100	30	15·120	5	15·120
30	15·100	1	15·120	30	15·115
57	15·110	30	15·110	6	15·115
30	15·115	2	15·105	30	15·110
58	15·110	30	15·100	7	15·110
30	15·100	3	15·115	30	15·110
59	15·105	30	15·125		

The top ef the weir is the zero-point of the gauge in the fore-bay.

Height of the Water after passing the Wheel.

Time.	Height, in Feet.	Time.	Height, in Feet.	Time.	Height, in Feet.
hrs. min. sec.		hrs. min. sec.		hrs. min. sec.	
4 56 0	2·20	5 0 0	2·21	5 4 0	2·22
30	2·21	30	2·21	30	2·21
57	2·21	1	2·21	5	2·21
30	2·21	30	2·21	30	2·21
58	2·21	2	2·21	6	2·21
30	2·21	30	2·21	30	2·20
59	2·20	3	2·20	7	2·22
30	2·21	30	2·20	30	2·20

The top of the weir is the zero-point of the gauge in the wheel-pit.

Height of the Water above the Weir by the Hook-Gauge.

Time. hrs.	min.	sec.	Height, in Feet.	Time. hrs.	min.	sec.	Height, in Feet.	Time. hrs.	min.	sec.	Height, in Feet.
4	57	5	1·8710	5	1	10	1·8690	5	4	35	1·8730
	58	15	1·8710		1	45	1·8700		5	50	1·8725
	58	50	1·8720		2	15	1·8720		6	25	1·8725
	59	20	1·8730		2	50	1·8720		6	55	1·8725
	59	50	1·8715		3	15	1·8715		7	20	1·8720
5	0	15	1·8715		3	40	1·8715		7	45	1·8715
	0	45	1·8705		4	5	1·8730				

The zero of the hook-gauge was 0·002 ft. *below* the top of the weir.

Direction of the Water leaving the Wheel.

Time. hrs.	min.	sec.	Direction. °	′	Time. hrs.	min.	sec.	Direction. °	′	Time. hrs.	min.	sec.	Direction. °	′
4	57	0	59	0	5	1	0	57	0	5	5	0	58	0
		30	57	0			30	59	30			30	59	30
	58		59	0		2		58	0		6		59	30
		30	58	0			30	57	0			30	57	0
	59		58	0		3		60	0		7		59	0
		30	58	30			30	58	0			30	57	30
5	0		57	0		4		59	0		8		59	0
		30	57	30			30	56	0					

When the vane pointed in the direction of the radius of the wheel, the reading of the index was 90°. 0° was in the direction of the motion of the wheel.

Previous to the commencement of the experiments, the apparatus for measuring the useful effect was carefully adjusted. The bell-crank was balanced when there were no weights in the scale. For this purpose the link M, Fig. 1273, was removed, and the chamber of the hydraulic regulator filled with water; weights were then applied to the top of the bell-crank, near the end to which the hydraulic regulator was attached, until the whole was in equilibrium; the final adjustment was made, by placing a weight of about 2 lbs. at the extremity of one of the horizontal arms of the bell-crank,—the arm was retained horizontally until a signal was given, when it was left at liberty to descend, and the time occupied in descending a certain distance was noted; the weight was then removed to the extremity of the other arm, and the same process repeated. The balance-weights were altered until the times of descent were equal. To overcome as much as possible the friction of the fulcrum, the pin forming it was lubricated with sperm-oil, and during the descent the head of the pin was struck lightly and rapidly with a small hammer.

After the bell-crank was satisfactorily balanced, the link M was reattached, and the brake adjusted by means of the screw which formed the connection between the link and the brake. It was adjusted so that a line upon the brake was perpendicular to the axis of the link, when the horizontal arm of the bell-crank was horizontal. The length of the brake was then measured upon this line.

	Feet.
The length of the brake as thus measured was found to be	9·745
The effective length of the vertical arm of the bell-crank was ..	4·500
And the effective length of the horizontal arm to which the scale was hung, was	5·000

Consequently, the effective length of the brake was $\dfrac{9\cdot745 \times 5}{4\cdot5} = 10\cdot827778$

The gauges in the fore-bay and in the wheel-pit were carefully adjusted by levelling from the top of the weir. This was repeated by different persons, so as to remove all chance of error.

The Hook-gauge was compared with the weir by a different method. When the regulating-gate of the turbine was shut down as tight as possible, it was still found that a quantity of water leaked into the wheel-pit, exceeding, a little, the quantity that leaked out of the wheel-pit, so that a small quantity continued to run over the weir. The principal leak into the wheel-pit was between the regulating-gate and the lower curb, the leather packing not being perfectly adjusted. The Hook-gauge was firmly attached to a post, placed in the wheel-pit for that purpose, and at a height known to be nearly correct. The regulating-gate was closed, and after the water had arrived at a uniform state, the height of the water at the Hook-gauge was noted, and, at the same time, the depths of the water on the weir were measured directly with a graduated rule. To perform this accurately, a board, about 4 in. long, was held by an assistant on the crest of the weir, at the place where it was intended to measure the depth; the author then applied the rule, previously well dried, vertically, on the top of the weir, in front of the board. On first immersing the rule, the water in contact with it did not stand at the true level of the surface, but formed a little hollow around the rule; it immediately commenced rising, however, and after a few moments came to a level, which was indicated by the reflection of a light from the surface, a lamp being held by an assistant, in a proper position, for that purpose.

The depths on the weir, taken in the manner just described, February 20, 1851, were as follows:—

	Depths on the westerly Bay of the Weir.		Depths on the easterly Bay of the Weir.
	inches.		inches.
	0·37	.. .. ..	0·36
	0·36	.. .. ..	0·36
	0·37	.. .. ..	0·36
	0·37	.. .. ..	0·36
Means ..	.. 0·3675	.. .. ..	0·36
Or in feet	.. 0·0306	.. .. ..	0·0300

While the heights given in the preceding Table were being measured, the depth by the Hook-gauge was constantly 0·0318 ft.; consequently, by this comparison, the zero of the Hook-gauge was 0·0012 ft. below the mean height of the top of the weir, in the westerly bay, and 0·0018 ft. below the mean height in the easterly bay, or 0·0015 ft. below the mean height in both bays. A similar comparison was made February 22, 1851, when the zero of the Hook-gauge was found to be 0·0024 ft. below the mean height of the weir. The mean of the two comparisons, or 0·0020, was adopted as the correction to be subtracted from the reading of the Hook-gauge, to give the mean depth upon the weir.

During the experiments, the levels of the water in the upper and lower canals were maintained nearly uniform. The height of the lower canal, at the place where the water, passing the weir, fell into it, varied a little, depending upon the quantity of water discharged by the wheel. It was highest when the wheel was running with the regulating-gate fully raised, and the brake removed; under these circumstances the surface of the water was from 0·3 ft. to 0·4 ft. below the top of the weir. In the other experiments with the regulating-gate fully raised, the fall from the top of the weir to the surface of the water in the lower canal was from 0·4 ft. to 0·6 ft. The brackets and the planks were not put on until after the turbine experiments were concluded, so that the water passing the weir met with no obstruction until it struck the water in the lower canal.

The obstruction caused by the planks was scarcely appreciable, which renders it certain that the effect of the lower canal, in obstructing the flow over the weir, must have been entirely inappreciable.

Emerson's Dynamometer-Brake.—A reliable dynamometer-brake, like that of James Emerson, Fig. 1281, which would show the amount of power transmitted at all times and under all circumstances, is a useful instrument. When the object is merely to ascertain the amount absorbed or required by a single machine, a series of machines, or a line of shafting, or the necessary means of transmitting power, a temporary attachment of the power-measurer, Fig. 1281, will be sufficient; but there are cases where a permanent attachment of the device is desirable. Such are all cases where the users of mechanical power are hirers, and pay so much for each horse-power used. The method of guessing or averaging, based on width of belt, size of pulleys, and weight of shafting, is hardly accurate enough where the cost of production of power is felt, as where the power is supplied from a steam-engine, or a water source liable to diminish in amount, or fail entirely. The dynamometer-brake should also be so simple in construction, and so exact in operation, as to be readily understood, and afford no possible or justifiable cause for controversy between hirer and letter of power. Such is the design of the device of Emerson.

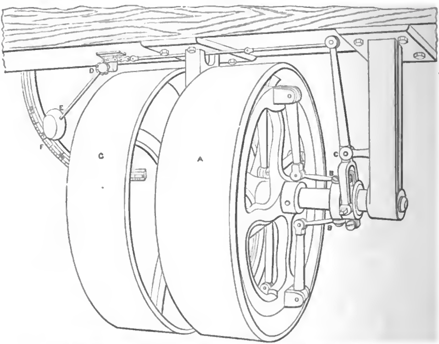
It is very simple in construction, and direct in operation. The pulley A is loose on the shaft, and receives the power. Its connection with the shaft is made by means of a wheel, keyed or screwed firmly to the shaft in close contiguity with the receiving pulley, its hub, in fact, forming one of the guides to the position of the pulley on the shaft. To connect this fixed wheel with the loose receiving pulley, a bell-crank lever is pivoted into projecting ears on the rim of the fixed wheel on opposite sides, the long arm of which connects with an annular slotted collar on the shaft by means of the short bars B. The short arms of the bell-crank levers connect on the inside of the fixed wheel with two radial bars, one parallel to the outer arm of the bell-crank, and the other at right angles to it, receiving near its upper end a pivot passing through a swivel hung to the rim of the fixed wheel, and having its extreme end pivoted to a stud fixed on the inner side of the rim of the receiving pulley. It will be seen from this description that the strain of the power received through the belt on A will necessarily react on the levers, and, through them, on the fixed wheel, which may be considered nothing more nor less than a support to these levers in sustaining them in position to connect the loose receiving pulley with the shaft.

At B it will be seen the levers are connected by pivots with the sliding collar, in the annular groove of which is seated a strap with which is connected a forked lever, the fulcrum at C. To the end of the long arm of this lever a rod with a short section of machine chain is attached. This chain runs over the cylindrical head D of a pendulum weight E, having a pointer that traverses a fixed quadrant F, properly divided by a scale to denote the relative pressure exerted through the medium of the receiving pulley on the shaft. The pulley G is fixed to the shaft, and delivers the power.

It will be seen that all the motions are absolute, there being no chance for play and back-lash, except that of joints and pivots; and this, by good workmanship, can be reduced to the minimum —too little to be taken into consideration practically. There is no dependence upon springs, spiral, or other forms, which are so liable to be affected by changes of temperature, and so unreliable between extremes of demand. It is a weighing machine as correct in principle as the old-fashioned steelyards or the platform-scales; in fact, it is simply a rotary platform-scale, and each machine may be weighed and tested in place by hanging to the pulley A sealed weights,

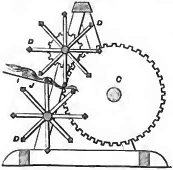
and marking the index as each weight is added. The lengths of the connecting-bars and chain are adjustable. The machine may be made of different sizes, and in different styles, suitable for testing all kinds of machinery. One kind especially adapted for spinning-frames, looms, &c.; another to be connected by belt to a line of shafting, or any kind of machine. And one especially adapted for testing turbine water-wheels, to which it is easily applied, with but comparative small expense.

1281.

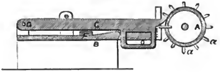


John F. Gilman's *Hemp-Brake* has an adjustable cross-rail I, Fig. 1282, secured to two inclined arms J arranged in front of the revolving beaters D in such a manner as to admit of the cross-rail being adjusted higher or lower when the hemp is passed over it on its passage to the beaters; the beaters being operated by means of the cog-wheel C.

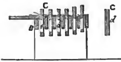
1282.



1283.



1284.



In the Flax and Hemp Brake of A. W. Hall, Figs. 1283, 1284, a bar F underlies all the beaters C, and by means of a lever-handle may be turned up edgewise to raise all the beaters evenly when

desired. The beaters, provided with openings C, knives and cutters d, and saws e, are operated by means of pins a placed in one or more spiral rows on a cylinder A in connection with the slotted bed B, and a suitable spring or springs, all arranged so that the beaters will work consecutively in pairs and perform the operations of braking, scutching and feeding simultaneously. The knives d and saws e are attached to a few only of the beaters on the discharge side of the machine to cut the flax or hemp, and also to separate the fibre from the woody portion, and divide it into finer threads.

1285.

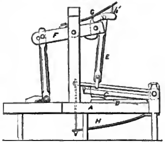


Fig. 1285 shows J. Bryant's Hemp and Flax Brake. A is the frame, B the bed, and H the treadle. The beater C is operated in such a manner that in the event of its being impeded by tough hemp or flax, it may yield, and thus avoid undue straining. To this end the rod E, which connects this water with the working-beam F, is pivoted at its upper end to a zig-zag bar h', which has a limited range of motion on a pivot which secures it to the beam. A strong spring G upon the top of the beam bears constantly on the zig-zag bar to hold it quite rigidly, but yet allow it and the beater to yield slightly when necessary.

Referring back to Fig. 1268, let E D be a drum, O its axis, and let the direction of rotation of the drum be in the direction of the arrow Q. Let p and q represent the tensions of the two ends of the strap A and B, respectively. The tension p exceeds the tension q by an amount equal to the friction between the strap B D E A and the drum D E. If c be put for the length of the arc of the flexible brake which embraces a greater or a less arc of the drum or pulley, then putting r for the radius of the circle D E, and f for the ratio of the friction to the pressure, we have the equation

$$p = q\,\epsilon^{\frac{fc}{r}}\,. \qquad [1]$$

To solve equation [1] for any of the quantities p, q, r, f, c, in a direct and simple manner has defied the skill of mathematicians who, with much labour and uncertainty, obtained results, from [1], by tables, two systems of logarithms, cumbersome series, and empirical formulas. However, equation [1] is readily solved, in a simple and direct manner without the use of tables, by dual arithmetic, a new art, invented by Oliver Byrne, the compiler and editor of this Dictionary.

From [1] we have $\downarrow, \left(\frac{p}{q}\right) = (100000000, f) \times \frac{c}{r}$; [2]. Since 100000000, = the dual logarithm of $\epsilon = 2\cdot71828183$.

Ex. 1.—Let $r = 32$ in., the radius of a drum; the coefficient of friction $f = \cdot473$; $c = 48$ in., the length of the arc of contact; the ratio of p to q or the value of $\frac{p}{q}$ is required.

From [2] the dual logarithm of $\frac{p}{q} = \frac{47300000, \times 32}{48} = 31533333$, which may be reduced to a dual number and the corresponding ordinary number found in a few minutes without extraneous aids. $31533333, = 3, 2, 9, 5, 0, 6, 6, 3, \downarrow, = \downarrow, (1\cdot3707161)$. Hence the ratio $\frac{p}{q} = 1\cdot3707161$ exactly; that is, if the tension $p = 411$ lbs., $q = 300$ lbs.

Ex. 2.—Required the length of the arc of contact c, without the use of tables, when $r = 10$ in.; the tension p equal four times the tension q; and the coefficient of friction $f = \cdot384$.

From [1] we have $\downarrow, \left(\frac{p}{q}\right) \times \frac{r}{(100000000)\,f} = (c)$; [3]. In this example $\frac{p}{q} = 4$, therefore, since $\downarrow, (2) = 69314718$, $(c) = \frac{138629436, \times 10}{38400000.} = 36\cdot10144$ in., the required arc of contact.

Byrne's 'General Method of Solving Equations of all Degrees;' 'The Young Dual Arithmetician;' 'Dual Arithmetic, a New Art;' 'Dual Logarithmic Tables.'

See Belts. Dynamometer. Friction. Gearing. Governor.

BRANDERING. Fr., *Revêtir les solives de voliges*; Ger., *Beschalen*; Ital., *Listellore un soffitto*.

Brandering is the covering of the under-side of joists with battens about 1 in. square in the section, and 12 to 14 in. apart, to nail the laths to, in order to secure a better key for the plaster of a ceiling.

BRAN-SEPARATOR. Fr., *Dodinage*; Ger., *Klei Sieber*; Ital., *Frullone*; Span., *Cedazo muy abierto*.

See Barn Machinery, p. 228, Figs. 544, 545.

BRASS. Fr., *Laiton, cuivre jaune*; Ger., *Messing*; Ital., *Ottone*; Span., *Azófar, laton*.

See Alloys, Antimony, Bismuth, Copper, Lead, Tin, Zinc. Aluminium, Arsenic, Manganese.

BRAZING COPPER. Fr., *Soudure de laiton*; Ger., *Hartlöthen*; Ital., *Saldare il rame*.

See Tin and Copper Plate Working.

BRAZING SOLDERS. Fr., *Soudures*; Ger., *Löthmittel*; Ital., *Saldatura forte*; Span., *Soldaduras*.

See Soldering.

BREAD MACHINE. FR., *Machine de boulangerie;* GER., *Backmaschine;* ITAL., *Macchina da far il pane;* SPAN., *Máquina para fabricar el pan.*

BREAD AND BISCUIT MACHINERY.

The process of bread-making is closely connected with that of fermentation. Wheaten flour consists, essentially, of starch and gluten, combined with a small portion of dextrine and sugar. The tenacity of *bread-dough* is due to the gluten present in the flour; the dough being produced by simply mixing the flour with a little water.

If bread-dough be tied up in a piece of fine muslin, and kneaded under a stream of water, the starch will be suspended in the water, having passed through the muslin; the gluten remains as a tough elastic mass, which soon putrefies if exposed to the air in a moist state, and dries up to a brittle horny mass at the temperature of 212° Fahr. Gluten is a compound substance, and is found to contain carbon, hydrogen, nitrogen, and oxygen, in the proportions, nearly, of 24, 20, 3, and 7 respectively.

When gluten is boiled in alcohol, a portion of it refuses to dissolve; this portion is termed *vegetable fibrine.* When this dissolved matter and alcohol are allowed to cool, a white flocculent substance, similar to the *caseine* which composes the curd of milk, is deposited. On adding water to this cold solution, the *glutine* is separated, which resembles the albumen found in considerable quantities in the blood. Although *gluten* presents three substances similar to the three principal components of the animal body, yet gluten separated from the flour by the process just described would be found very difficult to digest, on account of its resistance to the solvent action of the fluids in the stomach; for it is well known that *bread-dough,* composed of flour and water, even when baked, is indigestible. In order to render bread-dough fit for food, it must be rendered spongy, that is, porous, so as to expose a larger surface to the action of the digesting fluids; the most direct method of effecting this is the one adopted in the manufacture of *aërated-bread,* which consists in mixing the flour with water that is highly charged, under pressure, with carbonic acid gas; the mixing by this method is effected in a closed iron vessel, an aperture in the lower part of which is opened, then the pressure of the accumulated gas forces the dough out of the strong iron vessel into the air; the gas which has been confined in the dough expands and gives porosity and sponginess to the dough.

Another process for preparing *unfermented bread* consists in mixing the flour with a little bi-carbonate of soda; this mixture is then made into dough with water acidulated with hydrochloric acid; the bread is thus rendered porous. The chloride of sodium, formed at the same time, remains in the bread. In the making of cakes and pastry, the same object is attained by adding carbonate of ammonia to the dough. When baking, the salt is converted into vapour which distends the dough.

The tenacity of gluten, even in wheaten flour, is liable to variation; and in order to obtain good bread from a flour the gluten of which is inferior in this respect, it is customary to employ a small quantity of alum. This addition being considered unwholesome, it would be better to substitute lime-water, which has been found by Liebig to have a similar effect. Sulphate of copper improves in a very striking manner the quality of the bread prepared from inferior flour, but this salt is far more dangerous than alum.

Wheaten flour is particularly well fitted for the preparation of bread on account of the great tenacity of its gluten. Next to wheat, with respect to glutinous capacity, stands rye; whilst the other cereals contain a gluten so deficient in tenacity that they cannot be converted into good bread.

In the ordinary process of bread-making, the carbonic acid that confers sponginess upon the dough is evolved by the fermentation of the sugar contained in the flour; the flour having been kneaded with the proper proportion, usually about half its weight, of water, a little yeast and salt are added, and the mixture is allowed to stand at a temperature of about 70° Fahr. for some hours. The dough swells or *rises* considerably, in consequence of the escape of carbonic acid, the sugar being decomposed into that gas and alcohol, as in ordinary fermentation. The spongy dough is then baked in an oven, heated to about 500° Fahr., when a portion of the water and all the alcohol are expelled, the carbonic acid being, at the same time, much expanded by the heat, and the porosity of the bread increased. The granules of starch are much altered by the heat, and become more digestible. Although the temperature of the inside of a loaf does not exceed 212° Fahr., the outer portion becomes dry and hard, the hottest part being scorched into crust.

Instead of yeast, *leaven* is often employed, in order to ferment the sugar: leaven is a name given to dough which has been left in a warm place until decomposition has commenced.

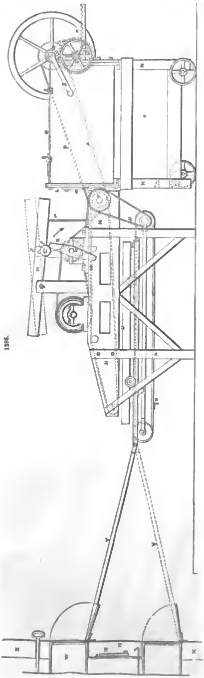
The passage of new into stale bread does not depend, as was formerly supposed, upon the drying of the bread consequent upon its exposure to air, but is a true molecular transformation which takes place equally well in an air-tight vessel, and without any loss of weight. It is well known that when a thick slice of stale bread is toasted, which *dries* it still further, the crumb again becomes soft and spongy as in new bread; and if a stale loaf be placed in an oven, it is reconverted into bread resembling new.

With William Watson's bread-making apparatus, Figs. 1286 to 1292, the entire operation, from the mixing of the flour and the other ingredients to the final deposit of the dough in the oven for baking, is performed by machinery.

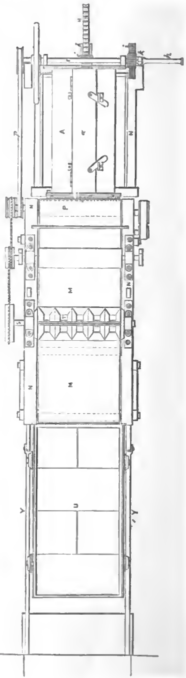
The mixer consists of a horizontal cylinder, with flanges at each end, and a door at the upper part, throughout its length, for introducing the materials, and through which the agitator or stirrer of the mixer may be removed. The cylinder is supported on suitable feet, and at one end is enclosed for about a third of its diameter by a fixed plate, which descends below the flange, and forms the base or foot at that end; the upper two-thirds of the cylinder end is closed by a sluice-door, which can be raised as required to form an opening for the exit of the dough. The other end of the cylinder is fitted with a piston, which forms a close end for the cylinder during

the mixing; this piston can be traversed in the cylinder, in which it fits sufficiently tight for the expulsion of the dough. An opening is made in the piston for the passage of an axis to carry the agitator of the mixer, which axis is carried by a bearing supported by a bracket from the flange of the cylindrical chamber; the axis at the other end passes through an opening in the sluice-door fitted with a bearing fixed thereto, or the bearing may be separately supported from the flange of the cylinder. The agitator of the mixer is made of a zig-zag kind of form, occupying the diameter of the cylinder, the several limbs of which extend across the diameter of the cylinder, and are all in the same plane, the angles at the extremities being all right angles, or nearly so. It has no central axis passing through it, being supported by a short axis at each end fitting into square holes in the extreme limbs of the agitator, which increase much in strength at those points. In order to strengthen and bind the several radial limbs or blades together, tie-rods are disposed in the direction of the axis, but distant about one-third the radius from the centre. The absence of the central axis prevents the dough collecting in the centre of motion. The limbs are inclined on both sides in opposite directions on opposite sides of the axis, in the manner of a screw, so that in rotating the agitator it forces the dough from one end to the other of the mixer, and on being reversed carries it in the opposite direction. The agitator is dropped in edgewise by a tackle at the door above, the ends of the cylinder being so adjusted that the bosses of the end limbs of the agitator bear hard against the ends and make the axis-holes dough-tight; the end limbs are also in close proximity to the ends, in order to scrape the adhering dough from them. The flour, water, and other ingredients having been emptied into the mixer, motion is communicated to the agitator by winch-handles at either end on the axis, or by means of a wheel and pinion. The dough having been mixed, the agitator and its axis are removed, and a long rack placed in the piston resting in a bearing, substituted for the axis-bearing, which is removed; a pinion is disposed to take into the rack, the axis of which pinion is carried by bearings on the flange, and if the machine is small, may be driven by crank-handles on the pinion axis, but if large, a multiplying toothed gear and fly-wheel shaft is used, by communicating motion to which the piston will be forced forwards by the rack, and the dough expressed as required; the same fly-wheel may also be made otherwise available when removed by placing it on the axis of the agitator. The sluice-door opens by means of a hand-lever, and is so adjusted as to emit the desired thickness of plastic dough, which is of a width proportionate to the size of the machine. The dough, when expressed, is received on an endless cloth moving on rollers and other supports, which is speeded to travel at the same rate as the expressed dough; in emerging, the dough passes under a duster, a perforated box containing flour receiving a lifting and dropping motion from a cam acting on a lever carrying such box; it then passes under a smooth roller, which smooths and reduces the dough to a uniform thickness, and under two or three rollers, if necessary. The thickness of dough which is sufficient for the substance of a loaf then passes under a rotating dividing cylinder, consisting of a series of dividing discs placed on a shaft; these discs are thick in the centre, but thinned towards the edge at the periphery, and present somewhat of a V form in a cross-section taken from the centre to the circumference; these discs are disposed on the shaft at distances apart, according to the size of the loaf to be made; there are also dividing edges placed between the discs, parallel with the shaft, separating the circumference into equal parts, which are two, three, or more in number, according to the size of the loaves to be formed and also to the diameter of the divider itself. This divider is driven at a speed uniform with the endless cloth, down upon which it presses and divides the plastic dough into loaves. It does not actually cut the dough, the dividing edges being rounded, but simply presses sufficiently deep creases in it to produce the subsequent separation required; thus the breadth of dough is cut up into a greater or less number of loaves, according to its breadth: after passing under the divider the divided dough passes from the endless cloth on to trucks to be conveyed into the oven. The cloth turns backwards under its carrying roller, from under which the trucks are pushed forwards at same rate as the dough travels, and these move on rails up to the oven-mouth. The cloth dips a little at the delivery end, and turns back under a very small roller, so that the drop of the dough on to the truck is very slight, and all moving at same speed it is readily carried away unintermittently as it is made, and the truck or car, which may or may not be of the length of the oven, is pushed forward on the sole until it occupies its position therein.

The oven is constructed of two, three, four, or more chambers, one above another, each of the width of dough delivered by the machinery; these chambers are of cast or wrought iron, placed between two brick walls, running from end to end of the oven, above the one chamber and below the other; the flues traverse from end to end, the longitudinal flues communicating alternately at opposite ends, so that the mouths of the several baking chambers or ovens are alternately at opposite ends, and must be filled in opposite directions. The fire and first flue is immediately under the chamber, and is considerably narrower than the chamber, in order to modify the heat; the succeeding and upper flues are wider than the lower one, but still considerably less than the width of the chambers, in order to prevent excess of heat at the sides near the brick walls, which would otherwise be apt to burn the bread at each side. When one chamber is full, the truck-carrying rails are shifted to a higher one, and the next truck is carried into the next chamber above, and so on until all the ovens are filled and the full batch delivered. Between the fire and lower flue and the first chamber is a cold-air flue, which protects the chamber from the immediate heat of the fire; the cold air traversing therein is admitted to the fire near the door, and supplies it with air with the door or blower closed, and so keeps the bakehouse cool. The trucks or cars consist simply of two parallel angle-irons, disposed and braced together at a sufficient breadth, and mounted on four or more wheels. The bottoms of the trucks are made of tiles or metal plates, which may have any given pattern, so as to impart an impression to the bottoms of the loaves placed thereon. The ovens are closed by doors that fall down and form a sole or stock-plate in front; the door being jointed to the sole of the door-frame in the manner of a butt-hinge, forms a close joint both with the door closed, and a level surface with the sole of the oven when open.



1236.



1237.

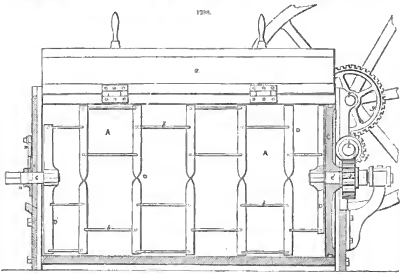
When baked, the bread is withdrawn from the oven, and may be broken asunder and handled and distributed as usual.

Watson, also, adapts this mixer to what is termed the expansion system of baking, that is, mixing the yeast with a small portion of the dough first, and such first portion with a larger portion, and so on. For this purpose an agitator is employed with a through axis and screw, and fixed radial arms therein, which have bevelled sides.

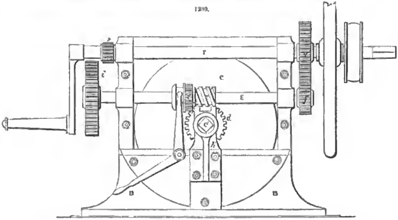
Fig. 1286 is a side elevation of this machine, which exhibits the arrangement of the one usually employed; Fig. 1287 represents a plan of the same with the dusting-box removed; while Figs. 1288 to 1292 represent some of the parts detached.

Fig. 1288 is a vertical longitudinal section of the mixing and expressing vessel; Fig. 1289 is an end view of the same at the end from which it is driven.

1288.

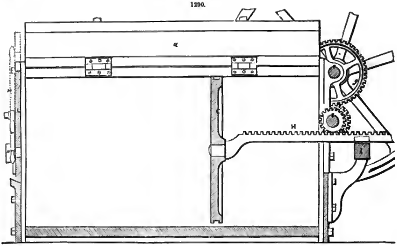


1289.

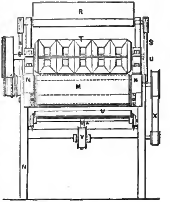


A is the cylinder or containing vessel of wood or iron; if of iron it should be lined with wood. It is mounted on feet or standards B, B, and is furnished with a hinged lid or cover *a*. C is the piston, which forms one end of the mixer, the other end being fitted with a sluice-door for allowing the dough to pass out. The agitator or mixer properly so called is formed of a series of pieces of iron united together by means of stays *b*, *b*. The pieces D, D, are twisted in opposite directions

1290.



1291.

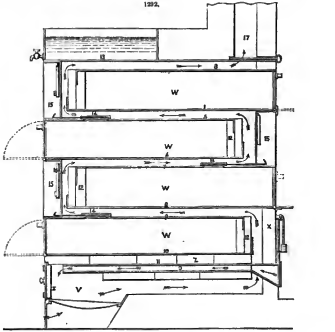


from the centre nf motion so as to form inclines or screw surfaces, which in rotating have a tendency to force the material on which they are operating in one directinn, that is to say, towards the end of the vessel; the end limbs D′, D′, are somewhat stronger than the others, and have bosses with holes in which short shafts *c*, *c*′, are inserted from either end, and motion being communicated to which causes the rotation of the mixer. To transit the motion a screw wheel or pinion *d* is fixed on the shaft *c*′; this gears into an endless screw *e* fixed on cross-shaft E. On this shaft is fixed a pinion *f* gearing into wheel *g*, mounted on the main shaft F, which may be driven by a winch-handle *h* or otherwise. The ingredients having been placed in the mixer, and mixed and treated as before described to form dough and bread, and after allowing sufficient time for the dough to rise, it is forced out of the chamber A in the following manner:—We remove the short shafts *c*, *c*′, from the agitator D, D, and lift it out of chamber A, and then close and fix the lid *a*. A rack H, Fig. 1290, is now placed in the piston C, which it fits into and rests in a crutch-bearing *h*′, formed on the top of the outside bearing of shaft *c*′. The pinion *d* is fitted to slide on shaft *c*′, but to carry it round with it by means of a feather. To communicate motion to the piston C, the shaft E is moved in the direction of its length, which has the effect nf throwing a pinion *e*′ fixed thereon into gear with the rack H, and at same time throwing pinion *f* out of gear with wheel *g*, and wheel *i* into gear with pinion *k*, which reduces the speed of rotation of shaft E, and the pinion *e*′ taking into rack H, imparts to it a longitudinal motion, and forces the piston C from its position at one end of the cylinder A towards the other end, and thereby compressing the dough in that chamber. To allow the dough to escape at the other end of the cylinder A, the sluice-door L is lifted up by a lever *m* to either of the dotted positions *m*, shown, the first being suitable for the formation, say, of 2-lb. loaves, and the second for 4-lb. loaves. The gland of bearing *n* of the shaft *c* is previously removed, and a solid plate substituted for it to prevent the dough being forced out thereat. The sluice-door L being lifted and fixed, say, at the lowest position, the dough contained in A by the pressure of the piston C will be forced out of the entire breadth of the opening of the sluice-door, and of regulated thickness, which will be contained in one uniform substance so long as any dough remains in the chamber A. From this chamber the dough is received on an endless web M, carried on rollers P and P′, mounted on a suitable framework N, N. The endless web M is further supported by a table Q, extending under the entire breadth, supporting the weight of the dough, which forms a continuous slab, so to speak. It travels at a uniform rate, the endless cloth M being driven at the same rate of speed as the dough travels by its expulsion from the chamber A. The cloth M is driven by a strap-pulley fixed on the axis of P′ and strap *p*, communicating with a rigger on the main driving-shaft E, and in its backward course underneath is rubbed in a tray containing flour to prevent the dough adhering. After emerging from chamber A, and while travelling on M, the dough is submitted to a dusting

operation from a dusting-box R, mounted above on a fulcrum q. This box or tray is the breadth of the dough, and has a perforated bottom. It contains flour, and preponderates on its fulcrum so as to fall against a stop or rest r. It is agitated by means of a double arm S, mounted on a rotating axis u, the arms coming in contact with a truck-roller t, mounted on the side of the dusting-box R. The axis u is driven by a strap from a rigger on same axis as P, and power is transmitted thereto by strap-riggers to an axis S', on which the divider T is mounted. This divider consists of a series of cutting ridges arranged in circular and longitudinal directions, the edges of which come down on the endless web, or nearly so. This divider is driven at about the same speed as the dough, which, on passing under it, becomes separated, or nearly so, into blocks of a given size, say, for 2-lb. loaves, which was the size before mentioned as arranged by the sluice-door L. If for larger loaves the mass of dough should be double the thickness, or another divider with larger cavities used. The several shafts are fitted in bearings in the framework N, and otherwise appointed, as shown in the figures. The divided dough, which is prevented sticking to the divider by the flour dredged on it, continues its course on the endless web M until it arrives at P'', where the divided dough Q is transferred to a truck U, disposed underneath in readiness for its reception. So soon as the dough begins to fall on to this truck, the truck also has a forward motion imparted to it, by a projection u on an endless strap v coming in contact with a projection w on the under-part of the truck. This endless strap is mounted on suitable pulleys, driven by a strap x from the axis of P'. The truck being mounted on wheels and suitable rails Y, travels along with its load towards the oven, which, as seen in the side view and plan, is immediately on end of the machine, so that as the truck is propelled forwards it enters the oven with its load of divided dough or loaves, and as the oven-chamber is by preference just the size to contain one truck, the oven-door is closed, and the baking proceeded with. Another truck is similarly disposed to receive the dough, and is carried forward into another chamber of the oven, and so on. The bottoms of the trucks, which are simply sheets of metal laid on the truck-frames, are roughened or indented, as seen in the plan, Fig. 1287, so as to imprint the bottoms of the loaves; they should also be dusted with flour to prevent the dough adhering. The rails Y are shifted for each oven-chamber, so as to rest on the door of each chamber, and conduct the truck to it. The truck having received its load of dough ceases to be propelled by the machine, but is pushed forward by hand into the oven, which is closed, and another one prepared with the rails to receive the next in succession.

Fig. 1292 represents a longitudinal section of an oven used with Watson's machinery.

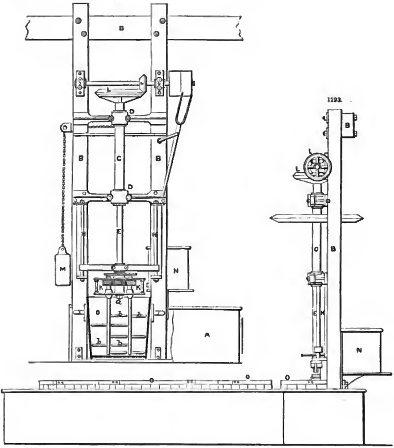
1292.



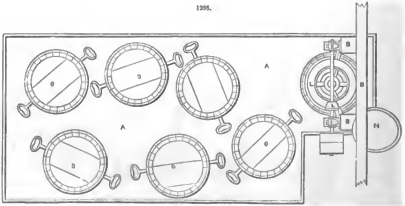
W, W, are the oven-chambers, which have their mouths alternately in opposite directions. They are formed between two brick walls X, X, the spaces being divided off by iron plates 3, 4, 5, to 11, the spaces between each pair of plates 3, 4, forming the flues to heat the oven-chambers, while below the plate 11 the furnace V is disposed. In order to protect the lower oven from the

1294.

1293.



1295.



immediate heat of the furnace, plate 11 is covered with a thickness of brickwork, or it may be both above and below, as seen at z, z, with an air-flue o through the middle, and of equal width with the fire, or nearly so. Air enters at the back end of o, which is regulated as required by a sluice-door to limit the supply to the fire through that channel: a constant change of air taking place in this channel assists in preventing the direct heat of the furnace overheating the lower oven-chamber. Z is the furnace-door. The flue from the furnace passes up in two branches, one on each side of air-flue o, at the end of the lower oven-chamber, then along above it under the second chamber, thence passing up at the end, and back under the third oven-chamber, and so on. To prevent excessive heat at the end of the oven-chambers, fire-lumps, as seen at 12, 12, are used to protect them, the metal plates of the oven being so made as to hold them in position. 13 is a water-tank, to be heated from the waste-head for bakehouse purposes; 14 is a slide-valve in the top of each oven-chamber, enclosed in a case except at the end that is not opposed to the draught of the flues. These valves are opened by thumb-rods when it is desired to allow steam to escape from the ovens; 15, 15, are hollow box ends of metal, closing the ends of the flues, by removing which the smoke-flues may be easily cleaned. These boxes being open from the outside are convenient for the insertion of thermometers, as seen at 16, to see and ascertain the heat of the ovens at all times. The escape of the flues to the chimney is at 17.

Vicar's Machinery employed in the Manufacture of Bread and Biscuits.—Fig. 1293 represents a side elevation of a soft-dough mixing machine; Fig. 1294 a front elevation; and Fig. 1295 a ground plan. Fig. 1296 is a side elevation of a breaking machine, which is employed for preparing the dough for the moulding machine. Fig. 1297 is a sectional elevation through Fig. 1298, which represents a top plan view of the moulding machine; Fig. 1299 is an end elevation. Fig. 1300 is a front elevation of a machine employed for moulding or shaping the dough into loaves or biscuits; Fig. 1302 is a ground plan of the dough-shaping machine; Fig. 1301, a sectional elevation. Fig. 1303 is an end elevation of Fig. 1302 at C.

On Figs. 1293 to 1295, A, A, is a tank or reservoir capable of holding water; B, B, is a framework, to which are connected the following parts:—C, a hollow shaft working in bearings in the castings D, fixed to the framing B; E is a shaft capable of sliding in the shaft C, and of rotating therewith near the lower part of the shaft E; a cross-head G is connected and slides on guide-rods H. I is a skeleton framing mounted loosely upon the shaft E, and connected thereto by a nut at *a*, Fig. 1294; K, K, are spindles, the upper parts whereof work in bearings in the framing I. The lower parts of these spindles are formed with prongs *b*. *c*, *d*, *e*, are wheels gearing into each other, that marked *c* is fixed on the shaft E, and those marked *d* and *e* are respectively fixed on the spindles K, K; L, L, is bevel-gearing for imparting rotary motion to the shaft C; M, a counterbalance weight connected by a chain *f* to the lower end of the shaft E, to facilitate the raising of E; N is a vessel to contain water to mix with the flour; O, O, are vessels in which the dough is mixed.

The operations of this machine are as follows:—The operator takes the ferment or yeast commonly used, and instead of mixing it in a trough by hand, as commonly practised, he places the yeast or ferment and flour in one or other of the vessels O, and, placing same under the machine, lowers the prongs *b* thereinto, and proceeds to impart rotary motion thereto, the effect of which is to cause the wheels *c* to rotate the wheels *d* and *e*, and also the axes K, on which the prongs *b* are fixed, thus producing three distinct rotatory movements simultaneously, namely, one rotation of the framing I, which carries the wheels *d*, *e*, and the axes of the prongs *b*, and another rotation of each of the wheels and axes and prongs, thereby effectually mixing and incorporating the ingredients together into a sponge; and when this operation has been continued a sufficient length of time, according to the judgment of the operator, he removes the tub O from under the machine, and places it in another part of the vessel, and taking another tub charges it with yeast and flour as before, and proceeds in this manner with each tub in succession. When the sponge is sufficiently risen or fermented, the tub is again brought under the machine, and the required flour and water added to the sponge, and made by the machine into dough. The dough is then left to *prove*, and when sufficiently proved is removed to the machine, Figs. 1296 to 1299, there to

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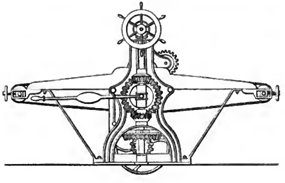

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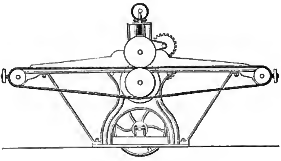

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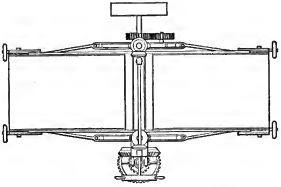

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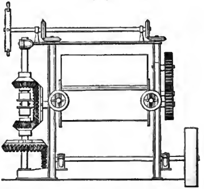

be operated upon by the brake-rollers of this machine for the purpose of taking the proof out of the dough. As regards this machine, Figs. 1296 to 1299, it should be distinctly understood that its construction forms no part of the machine shown in Figs. 1293, 1294. Both machines are described in conjunction, for the purpose of completing the description of the machinery necessary to be used in manufacturing bread, biscuits, and like articles. When the dough has been sufficiently operated upon by the brake-rollers it is removed from this machine to the shaping machine, Figs. 1300 to 1303, and operated upon thereby in the manner presently described.

We would here remark, that the means above described which we propose to employ, and have found to answer well in practice, for ensuring the proper amount of fermentation forms a very important feature in this invention, for by the use of cold water in hot weather we are enabled to prevent excess of fermentation, and by employing warm water in cold weather we can induce fermentation, the temperature of the water being regulated according to circumstances and the judgment of the operator.

We now proceed to describe the operations of the moulding or shaping machine. With respect

to the three rollers, marked A, B, C, Figs. 1300 to 1303, that marked A is employed to form the upper crust, and those marked B and C to form the lower crust, the soft dough being placed upon the table D, so as to pass with the two aforesaid crusts between the rollers E and F, by which the whole is compressed as the machine rotates, the endless travelling belt or web G advancing the dough under the moulding mechanism at H, where it is momentarily held still by the mechanism until the knives I descend and ascend by the action of the side rods K. The dough thus scored or shaped now passes onward by the action of the belt G, and when it comes under the stamps at L receives the impress therefrom of words, such as, for example, *machine-made bread*, this movement being simultaneous with the shaping movement with which it is connected; and in this manner the machine continues to mould and shape the dough into the form of loaves, which, as they are advanced forward by the endless belt or web G, are deposited on to trays, the trays being placed upon another endless belt or web N, the operation and construction of this part of the machinery and implements employed being as follows:—First, as regards the trays; they consist of flat pieces of wood, about 3 ft. by 2 ft., with ledges at the sides only thereof. Upon each of these trays is placed a piece of coarsely-woven cloth, and to each end thereof loops of tape, about 6 in. asunder, are affixed, and so as to project beyond the ends of the cloth about 2 or 3 inches, the loops being used for a purpose which will be described in another place. See OVENS. These trays, each with their respective cloth, are separately placed on the part M of the endless belt or web N, so that as this belt advances and comes under the part I of the belt or web G, the shaped

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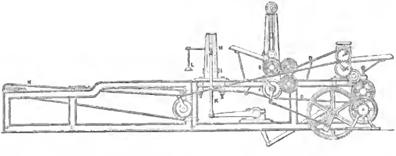

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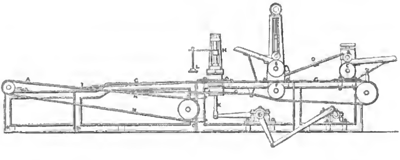

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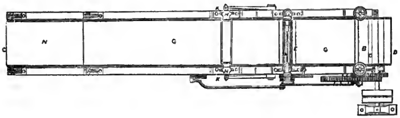

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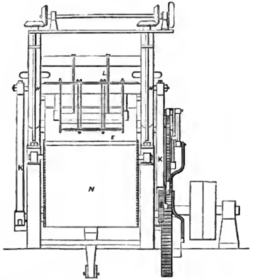

dough will he deposited on each of such said cloths and trays in succession, the operator dividing the dough when the tray is filled therewith; and in this manner several trays may be filled in succession.

See Barn Machinery. Mills. Mixers. Ovens. Yeast.

BREAKING JOINT. Fr., *Joint de recouvrement*; Ger., *Ueberdeckungsfuge, Deckfuge.*

Breaking joint, or *break joint*, is a term used in brickwork and masonry to express the arrangement by which the bricks or stones are made to everlap, the converse of which is termed "joint over joint." See Bond.

BREAKWATER. Fr., *Brise-lames, Jetée*; Ger., *Wellenbrecher*; Ital., *Murazzo, Scogliera*; Span., *Muelle, Espolon.*

See Harbours. Piers. Sea-Walls.

BREAST-WALL. Fr., *Mur de soutenement*; Ger., *Schüttemauer*; Ital., *Muriccinolo.*

A *breast-wall* is a wall bnilt up hreast-high, as a parapet-wall or a *retaining wall*, placed at the foot only of a slope.

BREAST-WHEEL. Fr., *Roue hydraulique de côté*; Ger., *Kropf Rad, mittelschlächtiges Wasserrad*; Ital., *Ruoto di fianco.*

See Overshot Water-wheels. Undershot Water-wheels.

BREASTWORK. Fr., *Fronteau*; Ger., *Schott, Schotting*; Ital., *Parapetto*; Span., *Repecho, Parapeto.*

See Fortification.

BREEZE. Fr., *Breeze*; Ger., *Lösche*; Ital., *Bragia.*

The term breeze is applied to ashes and cinders used instead of coal in the burning of bricks.

BREEZE-OVEN. Fr., *Four à Breeze*; Ger., *Coaks Ofen*; Ital., *Fornace da far arso.*

See Ovens.

BRESSUMMER. Fr., *Sommier*; Ger., *Unterzug*; Ital., *Trave maestra*; Span., *Sotabanco.*

A bressummer is a beam placed breastwise to support a superincumbent wall; used principally ever shop-windows to carry the npper part of the front, and supported on posts or columns.

BREWING APPARATUS. Fr., *Machines de brasserie*; Ger., *Braugeräthschaften*; Ital., *Macchine ad utensili da birraio.*

In making beer, the brewer first *mashes* the gronnd malt with water of a temperature of 176° to 182° Fahr., when the *diastase*, or substance containing nitrogen, operates to convert the mass into dextrine and sugar. The greater part of the starch, which has not been changed during the germination, and the *wort*, or new unfermented beer, is ready to be drawn off to be converted into beer. Brewers' grains, or the undissolved part of the malt, is employed to feed cows and pigs, as it contains much gluten.

To find whether malt contains more diastase than is necessary to convert its starch into sugar, it is only necessary to add a little fusion of malt to the viscid solution of starch; when this compound is maintained at a temperature of 150° Fahr. for a few honrs, and the diastase is in excess, the mixture will become far more fluid, and will no longer be colonred blue by solution of iodine.

Distillers take advantage of the excess of diastase in malt, by adding from two to four parts of

unmalted grain to the diastase, the whole of which becomes converted into dextrine and sugar, and thus the labour and expense of malting are avoided. The wort produced by infusing malt in water contains not only sugar, dextrine, and diastase, but a large quantity of nitrogenized matter formed with the gluten of the barley. Before subjecting the wort to fermentation, it is boiled with a quantity of hops, usually amounting to from $\frac{1}{50}$ to $\frac{1}{80}$ part of the weight of the malt employed. Hops are found to prevent the tendency of the beer to become sour: the sourness of beer is produced when the alcohol of the beer is converted into acetic acid. Hops contain from 9 to 10 per cent. of an aromatic yellow powder, termed *lupuline*, and is the active portion which contains a volatile oil of particular odour, together with a bitter substance. When the compound of wort and hops is run off into a vat, it is allowed to deposit the undissolved portion of the hops, then the clear liquor is drawn off into coolers, where the temperature of the compound is lowered as rapidly as possible to about from 58° to 61° Fahr.; the cooling is usually expedited by cold water circulating through pipes which traverse the coolers. When the wort is cooled too slowly, the nitrogenized matter which it contains undergoes a change from the action of the air, in consequence of which beer becomes acid. After cooling the mixture, it is placed in the *fermenting tun*, where the fermenting is carried on by adding *yeast*, which is about $\frac{1}{100}$ part of the compound.

It has been found, with the aid of the microscope, that *yeast* is a minute fungoid vegetable that grows in solutions containing sugar combined with particular nitrogenized substances, such, for instance, as a salt of ammonia, and the salts—phosphates of potash, soda, lime, and magnesia.

The conditions under which the yeast plant grows were not ascertained and scientifically examined until recently; for a long time, after the growth of this substance was ascertained, the seeds or germs from which it originates eluded detection, although its growth resembles some of the lower mosses.

The process of brewing may be divided into four distinct stages:—1. The *malting*, of which the object is to produce in the barley the principle which effects the conversion of starch into dextrine and glucose, and which essentially consists in causing the barley to sprout under the influence of a proper temperature and degree of moisture, diastase being formed at the origin of the sprouts, and in the succeeding operation converting the starch into soluble dextrine and glucose. 2. The preparation of the *wort* (moût), or saccharification of the malt, which consists in treating the ground malt with water at a suitable temperature, in order to cause the diastase to act on the starch and dissolve the dextrine and glucose which result from this action. 3. The boiling with hops, which consists in heating the wort with hops in order to give it a peculiar taste and aroma. 4. Fermentation, which consists in mixing the cooled wort with a ferment, in order to effect the conversion of glucose into alcohol.

The barley is first placed in large vats of mason-work, with four times its volume of water, being stirred frequently to expel the bubbles of air between the grains, while those which arise on the surface, being generally defective, are skimmed off. The object of this process is chiefly to swell the grains, in order that they may sprout more easily; and it lasts 24 or 36 hours in winter, during which time the water is renewed three times; while in summer it requires only 10 or 12 hours, but the water must be renewed four or five times.

The barley thus swollen is carried to the malt house, a kind of cave or cellar, the floor of which must be kept scrupulously clean to avoid all injurious fermentations. Germination requires the assistance of moisture, air, and a temperature of from 59° to 62°, which conditions are most readily realized in spring or autumn; whence the name of *March beer* is given to that made in the spring, and is considered superior to that made in any other season. In the malt house the barley is spread in a layer of about 1½ ft. in depth, and thus left until it becomes heated; but when it begins to sprout, the thickness of the layer is reduced to 1 ft., and then to 3 in. when the germination approaches the proper point. It is also frequently stirred, in order to renew the air in the interior of the layer. In the hot season, the germination is terminated in 10 or 12 days; while it requires 15 or 20 days toward the close of autumn, the sprout having then become two-thirds as long as the grain.

When the barley has properly sprouted, it is dried rapidly, in order to arrest the loss of the amylaceous matter which would ensue from a longer growth of the sprout and radicles. The drying is first made in the open air, by spreading the grain over the floor of a well-aired granary, and then in a stove traversed by a current of hot air, and called a *malt kiln*. Desiccation renders the radicles of the barley very brittle, but they are easily removed by sifting them in a *winnowing machine* or *fan*. The sprouted barley, thus freed from the radicles, is exposed for some time to the air, when it imbibes a small quantity of moisture, which facilitates its grinding. This operation is effected between horizontal stones, kept at such a distance from each other that the grain is broken and torn without being reduced to flour. The product is *malt*, which is stowed away for future use.

The saccharification of the malt is effected in large wooden vats, having a double bottom pierced with holes, intended to support the barley and facilitate the introduction and escape of the liquid. In the space between the two bottoms are the discharging-tube and one which conveys hot water. When the malt is placed in the vat, water at 140°, and equal in weight to one and a half times that of the malt, is poured in, the mixture being actively stirred with a kind of fork. It is then allowed to rest for half an hour, until the malt is thoroughly moistened, when water at 196° is added, until the temperature of the mixture attains 167°, which is the most favourable for saccharification; after which it is again stirred, the vat covered, and the reaction allowed to continue for three hours. The saccharine fluid, or *wort*, is then conveyed into a reservoir, and thence into the boilers intended for the decoction of hops.

As the first digestion with water only abstracts from the malt 0·6 of the saccharine matter it can furnish, an additional quantity of water at 176° is added, equal to one-half of that used in the

first operation, and is allowed to act for one hour, the liquid produced being added to the first. Lastly, the malt is exhausted by water at 212°, and a liquid obtained which is used in making small-beer. The exhausted malt (called, in this country, *grains*) is used as food for animals.

The wort is heated to ebullition with hops in boilers, which must be kept covered to prevent the escape of the essential oil, to which beer owes its aroma, and are furnished with an apparatus which constantly stirs the mixture. The strength of the wort is sometimes increased by the addition of glucose, molasses, or raw sugar. The wort, thus hopped, is conveyed into reservoirs, where it is clarified by rest, and then run off into other reservoirs, where it is cooled as rapidly as possible, by allowing the liquid layer only a thickness of 4 or 5 in.; the cooling vats being placed in large rooms surrounded by Venetian blinds, in order to afford a free circulation of air. The proportion of hops is about 1 kilogramme for every hectolitre of table-beer, and 2 kilogrammes for every hectolitre of strong beer.

When the wort is cooled, it is poured into a *fermenting vat* or *tun*, and a quantity of yeast added, varying, according to the season and strength of the wort, from 2 to 4 kilogrammes for every 1000 litres, and maintained at a temperature of about 68°. The fermenting house should be well aired, in order to allow the carbonic acid to pass off rapidly. The fermentation lasts from 24 to 48 hours, producing a large quantity of froth, which falls from the tun into spouts arranged for the purpose, and which, when collected and expressed in bags, constitutes *beer-yeast*.

The tuns are always kept full by adding the liquid separated from the froth. The fermentation of table-beer is completed in small casks filled to the bung, and placed on a scaffolding over a spout which carries off the froth still arising from the liquor; and when the fermentation is finished the kegs are plugged, and the beer only requires a clarification with fish-glue.

Strong beer is allowed to ferment slowly for several weeks after the fermentation in the tun, in large vats, holding as much as 2600 gallons.

See Attemperator. Barley-dressing Machine. Coolers. Distilling Apparatus. Elevators. Fermentation. Grain Measurer. Hop Back. Kiln. Liquor Boiler. Malt-dressing Machine. Malt House. Malt Mill. Malt Screen. Mashing Mill. Mash Tun. Refrigerator. Sparger. Stoves. Union Casks. Wort Copper. Yeast.

BRICK-MAKING MACHINES. Fr., *Machine de briqueterie;* Ger., *Ziegelpresse;* Ital., *Macchina da far mattoni.*

The Brick-making, Pugging, and Crushing Machine of H. Clayton, Son, and Howlett, is shown in Fig. 1304. The clay to be made into bricks is thrown into the hopper A of the machine. In this hopper revolves a shaft on which are keyed several small knives, which cut up the clay previous to its being crushed. It next passes through the crushing-rollers B, B, which effectually reduce to powder any stones or hard lumps of clay that may enter the hopper A.

The clay, thus partially prepared, next passes into the horizontal pug-cylinder C, where it is thoroughly mixed and incorporated by the pug-knives which are fixed upon the central shaft. These knives are so placed that they force the clay towards the farther end of the cylinder, where it is pushed by means of a rotary blade or piston, and taken by the small feeding-rollers D, D′. The mixture having been drawn by the small feeding-rollers D, D′, into the chambers, which are placed before the dies E, E, situated one on each side of the machine, the brick material issues through the rotary orifice dies in a smooth and regular stream, the angles well formed and the surfaces clean. It is then cut into bricks, of the required size, upon the cutting-tables F, F. This construction of machine is made of two sizes, and requires no masonry foundations, the whole being fixed upon cast-iron foundation-plates G.

The larger machines are worked by a 16-H.P. engine, and each is capable of producing from 20,000 to 30,000 bricks a day, varying according to the quality of clay used.

The smaller machine is generally worked by a 10-H.P. engine; this machine is capable of producing from 15,000 to 20,000 bricks a day.

In ordinary hand-made bricks, the main expense of the process of making, besides the burning, consists in the preparation of the clay, so as to render it sufficiently ductile to allow of its being forced into the moulds by hand-pressure; this necessitates the mixing of water with it, and thus requires also the further process of drying the bricks before placing them in the kiln. The risk of damage and the delay from weather also add materially to the expense of hand-made bricks. The application of machinery to the manufacture of bricks has for its objects economy, certainty, and expedition of production, and improvement in the quality and appearance of the bricks. It is still a question how far these objects have been attained; and out of the large number of machines invented for brick-making, but few are at present in regular work; omitting *tile and pipe-making machines*. The machines now at work may be divided into two classes—those which operate upon the clay in a moist and plastic state, and those for which the material requires to be dried and ground previous to being moulded. In the former class, the plastic column of clay, having been formed in a continuous length by the operation of a screw, pugging-blades, or rollers, is divided into bricks by means of wires moved across, either whilst the clay is at rest, or whilst in motion by the wires being moved obliquely at an angle to compensate for the speed at which the clay travels. In consequence of the clay having to be made sufficiently soft to allow of this wire-cutting, the bricks made are but little harder than those made by hand, and require similar drying before being placed in the kiln; and this drying, together with the expense of preparing the clay in the requisite manner, renders the expenses of manufacture similar to those involved in hand-made bricks. In the second class of machines, a superior finish of appearance is obtained in the bricks by their compression in a dry state in the mould; and the objection of subsequent drying is avoided: but the additional preparation requisite in drying the clay and reducing it to a sufficiently fine and uniformly pulverized state, and the more expensive character of the machinery involved, add materially to the cost of manufacture.

By means of the brick-making machine invented by a Mr. Oates, and described by John E. Clift in a paper read before the Inst. of Mechanical Engineers, the difficulty of previous prepara-

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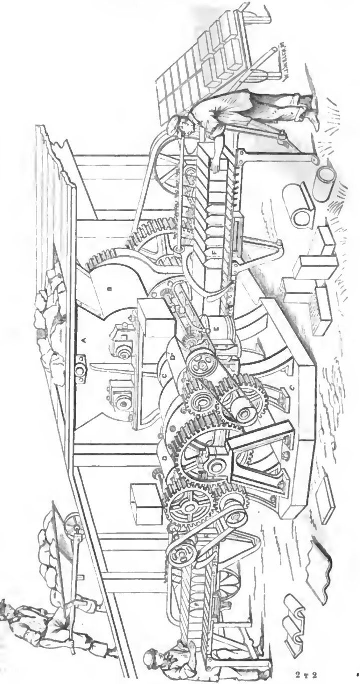
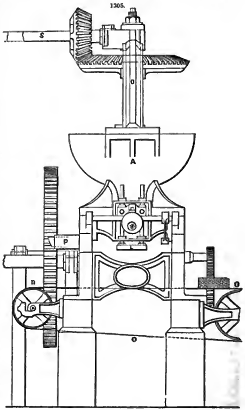


tion of the clay required in the second class of machines is not incurred; while at the same time the subsequent drying of the bricks required with the other machines is avoided. In this machine the clay is used of such a degree of dryness as to allow of its being mixed up and macerated and compressed into bricks by a single continuous action; the clay being formed into a continuous column and compressed into the moulds by the action of a revolving vertical screw. The clay requires generally no previous preparation beyond that given by the ordinary crushing-rollers, and is sometimes ready to be put into the machine direct from the pit; in other cases, where containing a mixture of stones, it is first passed through a pair of crushing-rollers.

The machine is shown in Figs. 1305 to 1311. Fig. 1305 is an end elevation of the machine; Fig. 1306 is a front elevation, and Fig. 1307 a plan; Fig. 1308 is a vertical transverse section enlarged; Fig. 1309 a plan of the screw; and Fig. 1310 is a longitudinal section of the machine.



The cast-iron clay cylinder A, Fig. 1308, is expanded at the upper part to form a hopper into which the clay is supplied, and the lower cylindrical portion is about the same in diameter as the length of the brick-mould F at the bottom of the pressing-chamber B. The vertical screw C is placed in the axis of the clay cylinder, and carried by two bearings in the upper frame D: this screw is parallel at the lower part, the blade nearly filling the parallel portion of the clay cylinder, and is tapered conically at the upper part to nearly double the diameter. When the clay is thrown loosely into the hopper, it is divided and directed towards the centre by the curved arm E revolving with the screw-shaft, and drawn down by the tapered portion of the screw into the parallel part of the clay cylinder, in sufficient quantity to keep this part of the cylinder constantly charged, any surplus clay easily escaping laterally into the loose clay in the hopper. The clay is then forced downwards by the parallel portion of the screw into the pressing-chamber B, and into the brick-mould F, which consists of a parallel block. This block is equal in thickness to a brick, and slides between fixed plates above and below; these plates containing the two moulds F and G, Fig. 1310, corresponding in length and breadth to the bricks being made.

The mould-block F, Fig. 1310, is made to slide with a reciprocating motion by means of the revolving cam H, which acts upon two rollers in the frame I connected to the mould-block by a rod sliding through fixed eyes; and the two brick-moulds are thus placed alternately under the opening of the pressing-chamber B to receive a charge of clay; the mould-block remaining stationary in each position during one quarter of a revolution of the cam H. When the brick-mould F is withdrawn from under the press-chamber, the brick is discharged from the mould by the descent of the piston K, which is of the same dimensions as the brick-mould; the piston is pressed down by the lever M worked by the cam N, when the brick-mould stops at the end of its stroke, and is drawn up again before the return motion of the mould begins. A second piston L acts in the same manner upon the second brick-mould G; and the discharged bricks are received upon endless bands O, Figs. 1305 to 1307, by which they are brought successively to the front of the machine, where they are removed to the barrows for conveying them to the kiln to be burned.

The solid block that divides the two brick-moulds F and G is slightly wider than the discharge-opening at the bottom of the pressing-chamber B, having an overlap, so that the making of one brick is terminated before that of the next begins, in order to ensure completeness in the moulding. During the instant when this blank is passing the opening at the bottom of the pressing-

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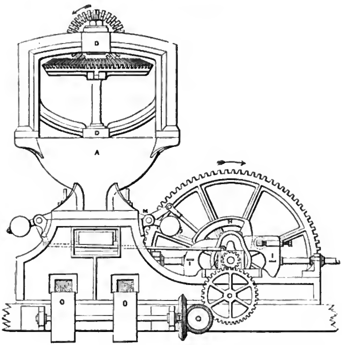

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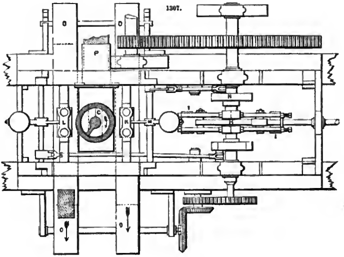

chamber, the discharge of the clay is stopped, and it becomes necessary to provide some means of either relieving the pressure during that period or stopping the motion of the pressing-screw. The latter plan would be impracticable; and in this machine the former mode is established by a very ingenious contrivance, forming in effect a safety-valve, which prevents the pressure in the chamber from increasing when the brick-mould is shut off, and also serves to maintain a uniform pressure during the formation of the brick, so as to ensure each mould being thoroughly and equally filled with clay. This is effected by an escape-pipe P, Fig. 1308, which is similar in form to the brick-mould, but extends horizontally from the side of the pressing-chamber, and is open at the outer extremity. The regular action of the screw forces the clay into this escape-pipe as far as its outer extremity, forming a parallel bar of clay in the pipe; the resistance caused by the friction of this bar in sliding through the pipe is then the measure of the amount of pressure in the machine; and this pressure cannot be exceeded in the machine, for the instant that the brick-mould is full the further supply of clay fed into the pressing-chamber by the continuous motion of the screw escapes laterally by pushing outwards the column of clay in the escape-pipe. The uniform pressure of every brick in the mould up to this fixed limit is ensured by the escape-pipe not beginning to act until that limit of pressure is reached. Its action is similar to that of a safety-valve; and the amount of pressure under which the bricks are made is directly regulated by adjusting the length of the escape-pipe.

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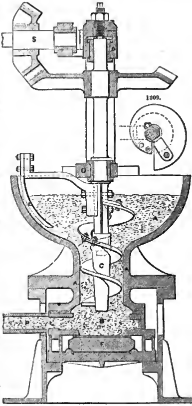
1309.



The important result of this arrangement is that it prevents any risk of over-straining the machine; and the action of the screw has a special advantage in filling the brick-mould with a continuous uniform stream of clay, which is being constantly supplied at a uniform moderate pressure, so as to ensure the mould being thoroughly filled with a uniform density of clay throughout, without requiring any sudden excessive pressure that would cause the brick to be more dense on the outside than in the centre. The pressing-chamber is made larger in transverse area than the supplying screw cylinder, in order to increase the uniformity of pressure on the clay in the chamber; and the regularity of action is shown by the working of the escape-pipe, which discharges a continuous bar of solid clay, advancing by intermittent steps of $\frac{1}{4}$ to $\frac{1}{2}$ in. of length each time that the brick-mould is shut off and changed. The projecting piece of clay from the end of the escape-pipe is broken off from time to time and thrown back into the hopper of the machine.

The upper side of the solid block separating the two moulds F and G is faced with steel, as shown in Figs. 1308, 1310, and the upper face of the brick is smoothed by being sheared off by the edge of the opening in the pressing-chamber; the under face of the brick is smoothed by being planed by a steel bar R, Fig. 1310, fixed along the edge of the under-plate, having a groove in it for discharging the shaving of clay taken off the brick.

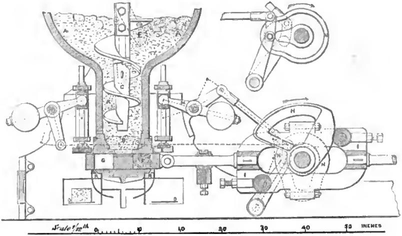
The screw-shaft is driven by bevel-gear from the shaft S, Fig. 1305, which is driven by a strap from the engine, the speed being adjusted according to the quality of the clay or the wear of the screw. The screw is driven at about thirty revolutions a minute, delivering the bricks at the rate of about 30 a minute when at full speed, or one brick for each revolution of the screw. The machine completes regularly in ordinary work 12,000 bricks a day, or an average of 20 good bricks a minute. The amount of power required for driving the machine and the wear of the screw vary according to the material worked. At the Oldbury Brick Works, where two of the machines have been working regularly for three years, the clay is a calcareous marl, and the power required for each machine is about 12 horse-power; the rate of manufacture is 20 bricks a minute.

The wear of the screw varies considerably, according to the material of which it is made and the quality of the clay worked in the machine. In a machine used by Peto and Betts at Cobham, cast-iron screws have been worn out in a short time with very siliceous material; but in two machines working at Gosport for two years, the screws were renewed only once in that time, although as many as three million bricks were made by the machines. In another machine

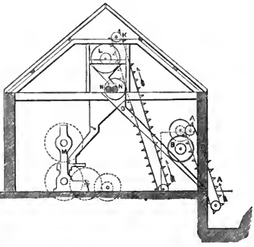
working for two years at the Blaenavon Iron Works, the screw and mould-block were made of gun-metal, and were found considerably more durable.

With regard to the burning of the bricks made by these machines, no difficulty has been found from the bricks not having been dried before stacking in the kiln; and a very small proportion of waste is made in the burning. Where the clay contains much alumina and retains more moisture in consequence, it is found advisable to stack the bricks in the kiln in *lifts*, as they are termed, of from fifteen to twenty courses each: as soon as the bottom *lift* has been stacked, small fires are lighted to drive off the steam from the bricks, which might otherwise soften those stacked above; the middle *lift* is then stacked and similarly dried, and then the top *lift*, after which the full fires are lighted. In other cases the whole kiln is stacked at once, and no difficulty has been experienced from the lower bricks not being able to bear the weight of the upper bricks.

1310. 1311.



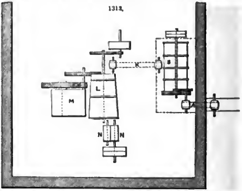
1312.



Sections, elevations, and details of Platt and Co.'s dry-clay brick-making machine are shown, Figs. 1312 to 1319. We take a description of this machine from a paper read before the Inst. of Mechanical Engineers, by B. Fothergill. The clay is taken from the bank in tramway trucks to a large shed or covered storehouse, which keeps the machines from injury while being worked in bad weather, when the clay cannot be got sufficiently dry. Under the shed floor is an arrangement of flues that can be heated to dry the clay as it is taken from the bank. From this shed the dry clay is taken by an elevator A, Figs. 1312, 1313, and shot into a hopper at the upper end of a revolving pulverizing machine B, consisting of a screen fixed at a slight inclination from a horizontal position, and so constructed and arranged that the clay is pounded and forced through it by crushers, while stones and other hard substances are ejected at its lower end.

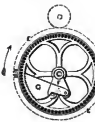
The pulverizer is shown enlarged in Figs. 1314, 1315. The fixed shaft C is set at a slight inclination from the horizontal, and the ends D D of the screen revolve upon it; to these ends are bolted the longitudinal bars E E round the circumference, forming the screen. These bars are of a wedge-shaped section, so as to give a wider opening between them on the outer than on the inner side, to allow the pulverized clay a free escape. There are also attached to the shaft C within the ends of the screen two bearers F F connected by two longitudinal bolts, which carry a series of cast-iron crushers or pulverizers G G, weighing about ¾ cwt. each: one bolt forms a fixed axis at the extremity of the pulverizers; and the other bolt acts as a support for them, in such a manner as to allow a slight space between their extremities and the inner side of the screen-bars E, to prevent actual contact when the machine may be working without clay. The screen is made to revolve at about twenty-five revolutions a minute by a pinion driving the wheel H fixed upon the upper end. The clay is fed in by the hopper I at the upper end, and by the rotary movement of the screen is carried forward and under the pulverizers G, which break up the lumps and press the clay out through the spaces between the bars E; but owing to the manner in which the pulverizers are arranged and supported, they yield and rise when stones or other hard substances are passing under them, preventing any damage to the machine: and in consequence of the inclination at which the screen is set, the stones are gradually traversed through its entire length, and ultimately rejected at the lower end which is left open for the purpose.

1313.

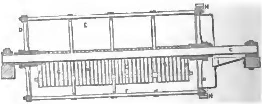


The clay is then conveyed from under the pulverizer by an elevator K, Figs. 1312, 1313, into a revolving conical screen or sifter L, shown enlarged in Figs. 1316, 1317; from which it falls into the hopper of the brick-press M, Figs. 1312, 1313, in a state of fine powder: any particles not passing through the meshes of the sifter L are rejected at its larger end and conveyed by a spout to a pair of small crushing-rollers N, and thence back by the spout O to the foot of the first elevator A, where they are mixed with the crude clay, and go through the same process again.

1314.

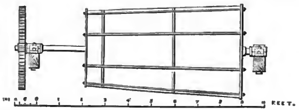


1315.



1316.

1317.

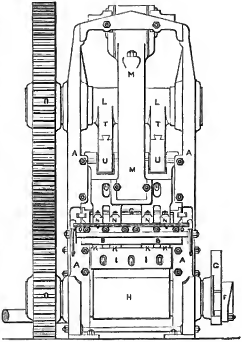


The brick-press is shown enlarged in Figs. 1318, 1319; Fig. 1318 is a front elevation, and Fig. 1319 a transverse section. The side cheeks A A are fixed on the foundation-plate and support the principal parts of the press. B is the frame or bed where the moulds are arranged and in

which the bricks are formed. C is the sliding mould-charger, to take the clay from the hopper D to the brick-moulds; an adjustable striker E is fixed upon the front of the hopper to gauge the charge of clay when being conveyed to the moulds by the forward motion of the lever F, which is actuated by the cam G, shown dotted in Fig. 1319, fixed upon the bottom cam-shaft H. The lower ram I rests upon and is actuated by the cam-shaft H, and is formed with four pistons K upon the upper surface: each of the pistons fits into a separate brick-mould. The top cam-shaft L gives motion to the upper ram M, which is also formed with four pistons N upon the lower surface, exactly corresponding with the four lower pistons K and fitting into the same brick-moulds. The two cam-shafts are driven at the same speed by the spur-wheels O which are driven by the pinion P.

The cams R S lift the upper ram M, and are so arranged as to produce two successive elevations and allow two falls of the ram and pistons in the formation of each series of four bricks made at each revolution of the machine. The first blow of the pistons, after being raised by the first cam R, drives the clay out of the four apertures in the mould-charger C, which have been brought directly over the four brick-moulds by the motion of the lever F; and compresses the clay into the moulds, thereby expelling the air from it: a very heavy blow is given by the pistons upon the clay, the total weight of the falling parts being nearly 1 ton. The pistons are then raised by the second cam S to a suitable height to allow the mould-charger C to move back to its former position underneath the hopper D, for the purpose of being filled with another charge of clay. A second blow of the pistons then takes place, thoroughly condensing the clay in the moulds; and the final pressure to finish the bricks is then given on the top side by the pressing cams T acting upon the friction-rollers U which are fixed on the upper ram M: this downward pressure is met by a simultaneous upward movement of the lower pistons K, given by the eccentric form of the bottom cam-shaft H. The shaft H is also formed so as to raise the bricks up to the top surface of the mould-bed B after the pressure is completed, whence they are removed to the table V by the forward movement of the mould-charger C, when delivering the charge of clay for the next set of bricks. An india-rubber buffer-spring X is placed in the upper ram M, to receive the concussion of the fall of the ram upon the cams R S, in case the machine should from any cause run without clay. By this arrangement of applying the pressure both below and above simultaneously, the bricks are kept in continued motion, sliding through the moulds whilst the severe pressure of the cams is taking place; which gives a fine polished surface to the sides of the bricks, and ensures the angles being all filled up completely square.

1318.



The faces of the moulds are formed of wrought-iron plates casehardened and secured by pins, so that they can be easily removed and replaced, when necessary.

The whole process is thus self-acting, from the crude clay being fed into the pulverizer out of the drying-shed, to the bricks being finished by the press ready for the *clamp* or kiln; and no waste of material takes place, other than the rejection of the stones by the pulverizer in the first process; and no process of drying the bricks being requisite, they are taken direct from the machine and stacked in the kiln ready for burning, thus avoiding all risk of damage from handling whilst in an unbaked state. The clay may be mixed with breeze or ashes, or chalk for white bricks, or other such substances, the machines working any sort of clay or mixture equally well; the press by its extreme pressure forms a perfect brick in an unburned state, and an uncommon hardness and closeness is obtained.

By this process of manufacture, within a quarter of an hour, clay may be taken from the shed in its crude state, and the bricks delivered by the press, taken by a tramway, and landed in the kiln ready to be burned in the usual way. Buildings have been erected with these bricks; and

it is found that with care in setting the bricks the inside surface is as perfect as the outside, and is finished without any occasion for plaster. For bricks so perfectly formed it might be expected that great care would be required in manipulation, and the production must necessarily be slow. The reverse is however the case, and the following is the result of actual working. The machinery prepares the clay and completes the bricks at the rate of 30 bricks a minute, or 1800 an hour; in one day of 10 hours' work 18,000 are produced, giving a total production of 5,400,000 a year of 300 working days. Thus with a very moderate amount of attention paid to burning, which is rendered easy by the great firmness of the bricks, 5,000,000 of perfect bricks may be burned from one machine in a year.

1319.

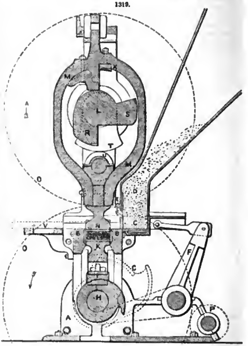
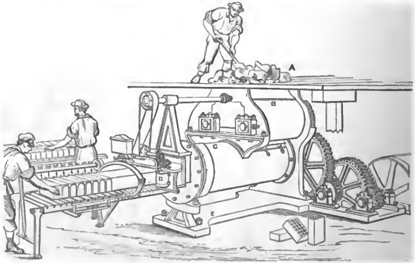


Fig. 1320 is of a brick machine, which requires from 6 to 8 horse-power to produce 12,000 to 18,000 bricks a day, according to the nature of the clay operated upon. This small machine of Clayton and Howlett crushes the clay, pugs the material, and moulds the bricks: it is a very complete machine.

The rough clay A is taken from the heap in barrows and wheeled up an incline, or it is drawn up the incline by suitable gearing by the power of the machine, and then shovelled into the feeding-hopper B, in which revolves a shaft which has several small knives fixed upon it; the duty of these knives is to cut up the large lumps of clay, and at the same

1320.

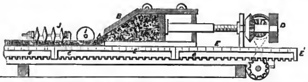


time to press it down upon the rollers incased in B, and further, to prevent the receiving-hopper from becoming choked.

The crushing-rollers next grip the clay, and crush all hard lumps and large stones, and force the thus partially-prepared material to the pug-cylinder C, in which revolves a strong shaft fitted with a number of knives, set in such a manner so as to form sections of a screw, which by their rotary action thoroughly *pug* or mix the *clay*, and at the same time force the homogeneous mass towards the end D of the cylinder, where it passes through the die or moulding orifice on to the cutting-off tables.

David Murtha's *brick machine*, Fig. 1321, has a series of rotating circular disks I, arranged so

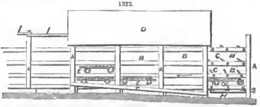
1321.



as to operate upon the clay, which, after being forced from the narrow opening *b* of the clay receptacle, is cut into strips of the proper width of the length of the brick. In front of the disks I is a transverse series of similar disks J, for the purpose of cutting the strips of clay into the proper widths. The feeding-table E′ E *e* is made in sections, so as to admit of being passed successively through the machine.

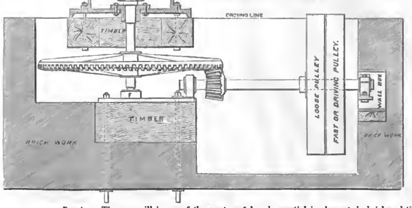
Fig. 1322 shows S. M. Parish's apparatus for *drying bricks*. It has a combination of adjustable supports G, to prevent the weight of the bricks from sagging the board, which rests on a carriage. A rod which connects

1322.



the slats is pivoted on journals, and used in connection with a carriage E and movable rails. B B are covered tracks; G H adjustable loading-stays; B′ B′ movable extension-rails; A A posts; I stringers; C the return tracks; and D the roof of the shed.

1323.



Pugging.—The pug-mill is one of the most useful and essential implements in brick and tile manufacture. The object of pugging the clay is to bring it into a complete homogeneous state of consistency. In the clay as dug, with rare exceptions, the strata are various. In some portions the unctuous, in others the sandy, siliceous, or other qualities prevail. In order to work brick-

clay properly and effectively, it is indispensably necessary to incorporate its various component parts, and to make it of one *uniform character*. The pug-mill is therefore the most valuable and important precursor of the subsequent processes of brick as well as of *tile manufacture*, inasmuch as the equal consistency and integrity of the raw material can alone ensure the uniform strength and good quality of the completed brick or *tile*. H. Clayton and Co.'s improved Archimedian knife pug-mill, Fig. 1323, produces these desirable results.

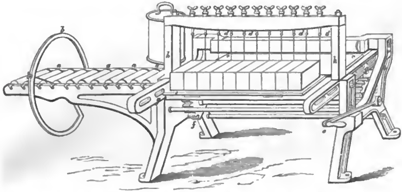
In Fig. 1323, A is a cast-iron cylinder into which the clay required to be pugged is thrown. Upon the central shaft B are fixed wrought-iron steel-tipped knives C, C, C, C (so placed as to form a section of a screw), which cut up and mix the clay, and at the same time force it downwards to the outlet D at the bottom of the cylinder, which can be adjusted with a sluice-door and lever for letting the clay out at certain times.

There is a door E, fastened with a strong wrought-iron bar, in the middle of the mill, for convenience, when it is necessary to inspect and clean the knives from roots and other foreign materials that may adhere to them.

The bottom end of the pug-shaft B works in a steeled bushed step F.

Clayton, Son, and Howlett's Brick-cutting and Self-delivery Table, Fig. 1324.—When a stream of clay of sufficient length to cut the desired number of bricks has been expressed from the die or

1324.



moulding orifice of the machine on to the receiving-rollers *a*, *a*, *a*, the single cutting-wire *b* is caused to pass through the stream of clay to sever or divide it. The desired length of moulded clay being now cut off from the mass, it is drawn forward by hand over the receiving-rollers on to the cutting or plate table *c*, in front of the cutting-wires *d*, *d*, *d*, so that the expression of the main stream of clay from the moulding machine may continue without interruption, whilst the severed portion intended to be cut up remains stationary.

This portion of the moulded clay is now ready to be cut up into bricks, which is done by causing the wires to pass through it by means of operating the handle *e*, which simultaneously transmits motion to the pinions *f f*, the racks *g g*, and the whole rack-frame *h h*, carrying with them the series of wires *d*, *d*, *d*, and also the plate-table *c* and platen or board *i*, causing the plate-table *c* to pass from under the clay through which the wires are passing, and to be replaced by the portable platen or board *i*. The handle *e* is now to be moved in the opposite direction, by which the whole movable parts described are returned to their original position, taking with them the clay now in form of cut bricks on the platen or board *i*: this platen or board *i* is then removed with the bricks upon it. Another board being substituted, the machine is now in position to repeat the operation.

One of the great advantages of this table over those previously in use consists in the perfect ease with which a large number of bricks can be cut and safely removed from the machine in a given time. This is effected, not by increasing the quantity of material coming from the moulding machine, but by the greatly-increased facility for the required operations, and by lessening the number of the waste pieces of moulded clay. It also wholly supersedes the risk and labour in the removal of the bricks from the machine. In other machines of the kind the cut bricks have to be removed from the table separately to place them on the barrow, rendering this portion of the operation subject to loss or damage of the bricks by negligence of the workmen.

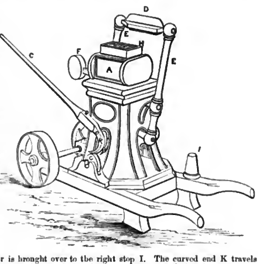
In this table these practical objections are avoided, as by its arrangement a positive number of (ten or twelve) bricks is cut and delivered, by one simultaneous operation, each time of cutting on to a receiving palette or board ready to be placed upon the brick barrow without the cut bricks having been handled in any way.

This table also possesses the advantage of being available for any variation of length of brick and for any required angle of cut, or for arch bricks, simply by removing the two strain-bars between which the wires are stretched, and by replacing them with other bars of the desired gauge, thus superseding the necessity of the outlay hitherto necessary for a series of separate cutting-tables. The action of this table is such, that whilst the wires are passing through the

clay, it is held true and firmly against a smooth metallic resistance-plate; thus the finish of the cut is clean and the ends of the bricks are square, and not left ragged or torn.

Hand-power Brick-pressing Machine, Fig. 1325.—This little machine of Messrs. Clayton and Howlett is the most perfect of the kind that has fallen under our notice. A is the mould box or chamber, in which a piston is moved up and down by means of partial revolution of a cam on the cam-shaft B, actuated by the hand-lever C; this cam-shaft is connected with the top-cover D by the side arms E, and moves up and down with it, but when pressing is free to reciprocate on its own centre without moving the cover or side arms. F is a weight attached to the cam-shaft, and vibrates with the hand-lever C, which being sharply thrown over, adds considerably to the pressure by its own momentum. G is a friction-roller on which the curved end of the hand-lever works when delivering the bricks, and by pulling the hand-lever over in the position shown in the engraving, the whole of the cam-shaft, with the side arms and cover, are bodily raised, and the piston is brought up flush with the top edge of the mould-box. The rough brick H to be pressed is now placed upon the piston, and the lever is brought over to the right stop I. The curved end K travels upon the friction-rollers, and the whole cam-shaft, side arms, top-cover, and the piston with the brick, are lowered until the lever arrives at a perpendicular position, by which time the cover has been brought into its proper position on the top of the box by the guides; the cam-shaft is now entirely supported by the side arms and cover, and simply reciprocates upon its own centre, which motion causes the cam to raise the piston and compresses the brick. The lever is now thrown sharply back to the opposite side, which action causes the curved end of the lever to ride upon the roller, and bodily raises the cam-shaft, the top-cover, and the piston, and delivers the brick ready to be taken away.

1325.



One of the great features in this press is the patent self-lubricating piston, whereby a great saving of time is effected, and the great desideratum of preventing the adhesion of the brick to the mould has been obtained.

The process of washing is resorted to for the effectual separation of limestones and other substances from earths into which they, injuriously to the manufacture of clay wares, intrude; or for those classes of bricks, such as London stocks, with which for a special object chalk is largely mingled with the clay. For such object Roller and Harrow Wash-Mills are much used, and they are applicable separately as chalk-mills. These mills are also used in cases where a special manufacture renders the washing of the clay, or of the whole of the raw material, necessary.

1326.

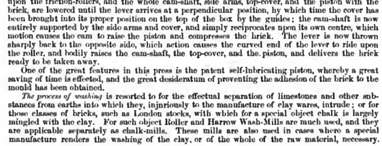


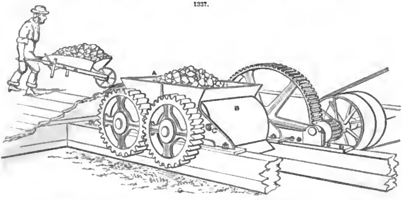
Fig. 1326 represents a cross-section of one of Clayton and Co.'s Clay and Chalk Washing-Mills; there are two races D, C, the minor one D for chalk, and the outer C for clay. A is a central iron shaft,

supported at the top, bottom, and centre by the steps V, W, W'; to this shaft is fixed a 6-way beam-socket Y, into which are fitted and secured six harrow beams, two of which are shown at E, E, Fig. 1326, radiating from Y. Upon these beams E, E, are fastened harrows F, F, by means of chain sliegs g, g, which when the mill is at work permit of the harrows making a zig-zag motion. The chalk race D is furnished with three spike-rollers, one of which is shown, in Fig. 1326, at H. Besides the harrows we have mentioned, there are two others attached to their respective beams E in the chalk race D.

The ends of the harrow beams E are supported by tie-bolts K, K, K, K, which are secured to a lug-ring b at the top of the centre shaft A. The tie-bolts are carried through the lugs on the beam-caps p, and can be tightened up when required by the nuts at p. Scrapers T T are fixed at the ends of the beams to keep the sides of the races clean. Motion is given to the central shaft through a bevel-pinion R on the lay shaft S and bevel-wheel O keyed on the central shaft A. This bevel-wheel O works on antifriction rollers P, P, fitted beneath it. Chalk is thrown into the hopper B (secured on to and revolving with the beams E), and passes into the chalk race D, where water is introduced. The material becomes quickly liquefied, and passes through the apertures Z Z into the clay race C, wherein is thrown the clay, &c., required to be washed, which is here worked by the harrows, reduced to a thick liquid state, and amalgamated with the chalk water. The limestones precipitate, and the liquid mixture is let off through the sluice L and outlet M to the "back," or reservoir, where it remains until of suitable consistency for being moulded.

Crushing.—In Fig. 1327 A is the receiving-hopper of Clayton's Clay-crushing Mill, into which

1327.



the earth requiring to be crushed is thrown. B, B', are cast-iron chilled rollers, bored and keyed upon wrought-iron shafts, which work in gun-metal bearings. The rollers B, B', may be set nearer or closer, as desired, by means of the set screws C, C', so that the stones and lumps of hard clay may be crushed as well as the finer material. The machine is fixed upon a strong timber framing; round the receiving-hopper A a platform is usually erected for the convenience of wheeling the clay to the mill.

Vertical Pugging and Moulding Machine.—The machine of which Fig. 1328 is a side elevation and Fig. 1329 a plan, is sometimes termed a *two-process* brick-making machine. This machine of Clayton and Co. is very substantial and complete; C is a cast-iron vertical cylinder fitted at top with a sheet-iron hood or guard H (for convenience in feeding), mounted and bolted firmly upon a strong cast-iron framework F F and foundation-plate F'. S S are two side frames, also bolted to framework F F and to foundation-plate F', whose duty is to carry the expressing or mould-feeding rollers R R. The vertical cylinder C is furnished with a strong, square, wrought-iron pug-shaft S¹, turned at ends, and into which are fitted and secured single wrought pugging-knives or blades B B B B, so disposed as to form sections of a screw, and at bottom of the cylinder one double delving-blade or sweeper D, forged in form of §. Motion is given to this pug-shaft S¹ by means of bevel-wheel W, keyed upon the vertical shaft, and pinion W fitted upon the pulley-shaft A underneath the cylinder-plate F. The vertical shaft S¹ runs in a step T bolted to the foundation-plate F¹, and is supported by a collar B¹ in the cylinder-plate F, and also by a bridge-bar B² fitted at the top of cylinder, thus rendering the whole substantially rigid. A sluice-valve V is adjusted at the bottom and outside of the cylinder C, opposite to the expressing-rollers R R, fitted with regulating-screw and wheel S². Two wrought-iron carriage-bars C' C' are bolted to cylinder-frame F F and roller-frame S S, into which are fixed small rollers R' R', making a framework bridge for the passage of the pugged earth from the sluice-valve V to the rollers R R.

P P are segmental packing-pieces of wrought iron inserted in suitable recesses inside the roller side frames S S fitted with set screws, so that they may be pressed against the ends of the rollers R R, to prevent the passage of the clay between the rollers and the side frames, and compensate for the wear of these parts. The rollers R R receive motion by suitable strong spur-wheel gearing from the horizontal pulley-shaft A and pinion P', through the intermediate shaft

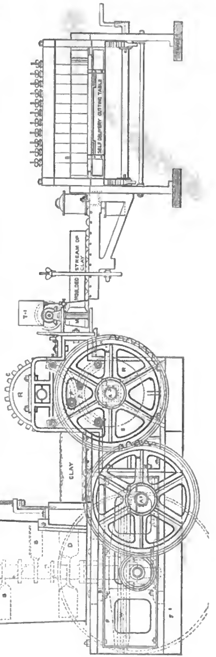
A^2 and wheel E to lower feeding-roller shaft A^3 and wheel E', the top roller being geared on the opposite side by a pair of spur-wheels G G.

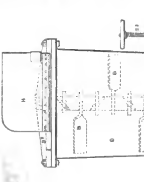
N N are steel scrapers with regulating-screws fitted upon the delivery mouth-piece of the machine, for cleaning the rollers as they revolve.

In front of the delivery mouth-piece is attached the rotary die or mould, of which M M are the rollers, which are covered with cloth or fustian. These side moulding-rollers are driven by small bevel-wheels and horizontal shaft N on the top side of the die, receiving motion from the lower roller-shaft A^3 by pulleys and belt. A water-tank T^1 is attached over, fitted with pipes and regulating-cocks, for keeping moist the cloth-faced rollers M M, to prevent the clay adhering thereto as they rotate. In front of the rotating die or moulding orifice is shown the self-delivery cutting-table, of which a description has already been rendered.

The brick-making machinery, invented by Henry Large, which is employed to make hard bricks, and especially those which do not require burning, is illustrated by mechanical drawing, Figs. 1330 to 1337.

The materials of which the bricks are to be made when properly mixed are placed in a mould, which is then brought under a plunger worked by a crank-pin, eccentric, or other equivalent mechanical device, whereby the materials in the mould will become consolidated and compressed into the form of a brick. The mould with the compressed brick therein is then carried forward to a second plunger, the rod of which is connected by a rocking lever to the rod of the first plunger, so that immediately after a brick has been compressed the brick that has just been passed forward will be by the descent of the second piston forced out of the mould on to a receiving-table attached to the end of a weighted lever, from which the finished brick is removed by hand, and then the table is carried up by a weighted lever into its original position, ready to receive another brick.





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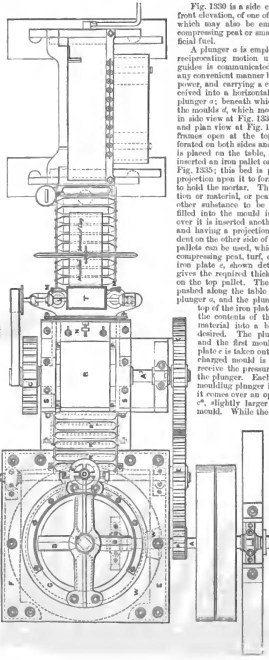
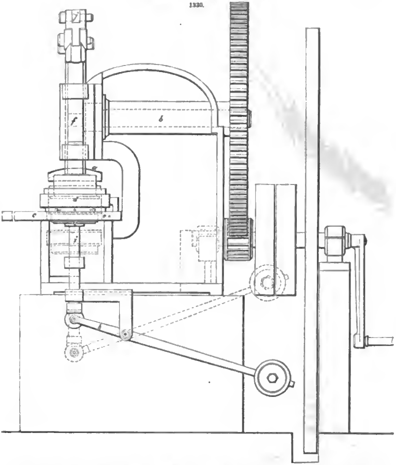


1329.

Fig. 1330 is a side elevation, and Fig. 1331 a front elevation, of one of Large's brick machines, which may also be employed for moulding or compressing peat or small coal into bricks of artificial fuel.

A plunger *a* is employed, to which a vertical reciprocating motion up and down in suitable guides is communicated by an axis *b* driven in any convenient manner by steam, horse, or manual power, and carrying a crank-pin *b**, which is received into a horizontal slot in the stem of the plunger *a*; beneath which is a table *c* to support the moulds *d*, which moulds are shown detached in side view at Fig. 1332, end view at Fig. 1333, and plan view at Fig. 1334, and are rectangular frames open at the top and bottom, and perforated on both sides and both ends. The mould is placed on the table, and into it there is first inserted an iron pallet or bed, shown detached in Fig. 1335; this bed is perforated, and having a projection upon it to form an indent in the brick to hold the mortar. The brick-making composition or material, or peat, turf, or small coals, or other substance to be operated upon, is then filled into the mould in suitable quantity, and over it is inserted another pallet also perforated, and having a projection upon it to form an indent on the other side of the brick. Or plain iron pallets can be used, which would be the case for compressing peat, turf, or small coal. Then the iron plate *e*, shown detached Fig. 1336, which gives the required thickness to the brick, is put on the top pallet. The mould thus charged is pushed along the table *b* and brought under the plunger *a*, and the plunger coming down on the top of the iron plate *e* powerfully compresses the contents of the mould and forms the material into a brick, or any other form desired. The plunger immediately rises, and the first mould is pushed on, and the plate *e* is taken out, whilst another similarly charged mould is brought into position to receive the pressure at the next descent of the plunger. Each mould after passing the moulding plunger is pushed outwards until it comes over an opening in the table, as at *c**, slightly larger than the inside of the mould. While the mould is resting on the table *c* it receives a second plunger at the lower end of the rod *f*, whereby the brick or substance in the mould is forced out of it on to a palm *g*, which is held up against it by a counterbalance weighted lever *h* acting against the lower end of the vertical rod *i*. The second plunger has a reciprocating vertical motion given to it by means of a link, whereby it is connected to a rocking lever *j*, the opposite end of which is similarly connected to the rod of the first plunger *a*. The finished brick or substance in the mould, together with the bottom and top pallets, remain on the palm *h*, their weight being sufficient to keep

1338.



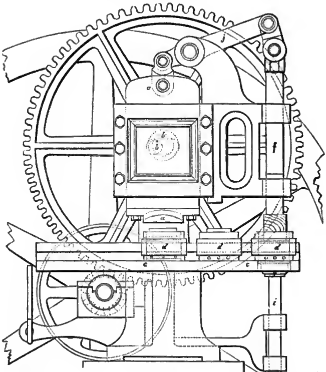
the palm down. As each brick or substance is removed the palm *h* again ascends to receive the next brick, and the empty mould is conveyed away to be refilled. On the same principle that one brick or substance is compressed in the manner described, two or more can be made at one stroke by using several plungers, and also can be driven out of the moulds by a second set of plungers.

Figs. 1337, 1338, show another arrangement of Large's machine. The bricks made by this machine are not burnt, but merely mixed, in proportions of sand and cement, and pressed into moulds of the required size; they are then laid on the ground or on shelves for forty-eight hours, to harden, after which they are stacked in the open air, exposed to the weather, and in fourteen days are ready for use. These bricks increase in hardness for twelve months, after which they resist the action of frost, and do not absorb moisture. The first patent for making concrete bricks was that of Hustwayte and Gibson, in 1853. In 1856 L. D. Owen introduced a plan of making concrete bricks which has been worked most successfully in South Wales. In the town of Newport many of the houses are built of these bricks, and one firm in the town manufactures 50,000 a week.

Thomas Don, the eminent machinist, gives the following as the result of some experiments by hydraulic pressure:—

	Showed 1st flaw. Tons.	Crushed at. Tons.
1. A stock brick, as ordinarily made, cracked at	$1\frac{3}{8}$	8
2. A compressed concrete brick, composed of 1 part cement and 6 parts coarse sand, 14 days made	10	$18\frac{3}{16}$
3. Hand-made concrete brick, 1 part cement, 6 parts burnt *ballast* and hoggin mixed, made 7 weeks	7	$17\frac{5}{16}$
4. A malm paviour, very well made and burnt	5	$31\frac{1}{4}$

1331.



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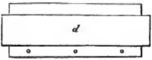

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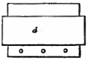

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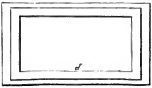

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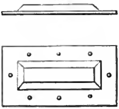

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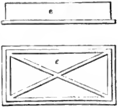

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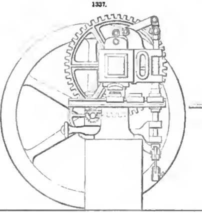

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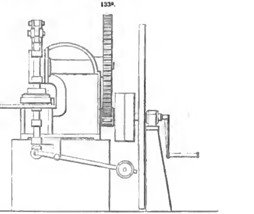
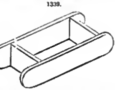


Moulding of Bricks.—The *mould*, Fig. 1339, for forming the bricks is $\frac{1}{12}$ to $\frac{1}{10}$ larger than the size of the brick to be made, as the clay shrinks in burning.

Brick-moulds may be made of any hard wood, which should be thoroughly seasoned, and the edges, which wear very fast, should be protected by a thin strip of iron. Moulds should be frequently gauged, especially when the brick-makers find their own moulds, or the bricks made will vary very much in thickness. Brick-moulds are now made lined with brass, which shows the importance attached to the correct moulding of bricks.

1339.



Two methods of moulding are employed, namely, *slop* and *sand* moulding. In the former the mould is dipped in water every time it is used; in the latter it is sprinkled with fine sand, or with ashes from an old brick kiln. In either case the brick-earth should not be used too wet; and it should be pressed carefully and thoroughly, so as to fill the moulds. The superfluous earth is then removed by a *strike*, which is a straight-edge of wood or metal passed along the top of the mould, and pressed well down on its edges. Steel strikes are best, as wooden ones are cut by the edge of the brick-mould, and then scrape away too much of the surface of the brick, thereby rendering its thickness irregular.

Bricks made by hand are moulded on boards or benches; in India, mostly on the ground, which should be made as smooth and even as possible. At Roorkee, smooth plastered terraces have been used, the surface sprinkled with fine sand or ashes. The bricks are moulded side by side till the terrace is covered; they are then left on it till dry enough to be turned on edge without loss of shape; then, after another short interval, stacked, or, as it is called, laid in a *hack*.

Drying.—The bricks should be left in stack until thoroughly dry, as, if put into the kilns damp, the strong heat of the kiln will dry them too suddenly, and probably split or partially disintegrate them.

In drying bricks, they must be protected from the sun, wind, rain, and frost; and each brick must be dried uniformly from the surface to the centre.

Slop-moulded bricks are usually dried on flats or on drying-floors, where they remain from one day to five or six, according to the state of the weather. When spread out on the floor they are sprinkled with sand, which absorbs the superfluous moisture, and renders them less liable to crack in the sun. After remaining on the floors until sufficiently hard to handle without injury, they are built up into hacks under cover, where they remain from one to three weeks, until ready for the kiln. In wet weather they are spread out on the floor of the drying-shed, and great care must then be taken to avoid draughts, which would cause the bricks to dry faster on one side than the other. To prevent this, boards set edgeways are placed all round the shed to check the currents of air.

The ground required for drying bricks in this manner is comparatively small, as they remain on the floors but a short time, and occupy little space when hacked in the hovels. The produce of a single moulding-stool by the slop-moulding process seldom exceeds 10,000 a week, and the area occupied by each stool is, therefore, small in proportion. Half an acre for each kiln may be considered ample allowance for the working floor and hovel.

In places where brick-making is conducted on a large scale, drying-sheds are dispensed with, and the hacks are usually built in the open air, and protected from wet, frost, and excessive heat, by straw, reeds, matting, canvas screens, or tarpaulins.

Bricks intended to be clamp burnt are not dried on flats, but are hacked at once on leaving the moulding-stool, and remain in the hacks much longer than bricks intended to be kilned. This is rendered necessary by the difference between clamping and kilning. In the latter mode of burning,

the heat can be regulated to great nicety; and if the green bricks, when first placed in the kiln, be not thoroughly dried, a gentle heat is applied until this is effected. In clamping, however, the full heat is attained almost immediately, and, therefore, the bricks must be thoroughly dried, or they would fly to pieces.

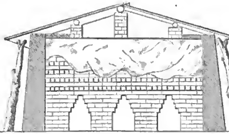
We append some useful directions and practical remarks on the burning of bricks, taken from 'The Roorkee Treatise on Civil Engineering,' edited by J. G. Medley.

The *burning of bricks* is an operation of great nicety, because if not burnt enough they will be soft and worthless, and if overdone, they vitrify, lose their shape, and often run together so as to be inseparable and useless. Various methods have been adopted for producing the due degree of firing. In general, bricks are burnt, both in America and England, in a brick kiln; but in London, the burning constantly takes place in the open air, the bricks being made up into immense quadrangular piles or clumps, consisting of from 200,000 to 500,000 bricks in each. In India both kilns and clamps are used.

English Kiln.—A *brick kiln*, as usually constructed, is formed of bricks built in a square form like a house, with very thick side walls, and a wide doorway at each end, for taking in and carrying out the bricks; but these doors are built up with soft bricks laid in clay, while the kiln is burning, and a temporary roofing of any light material is generally placed over the kiln to protect the raw bricks from rain while setting, and so made that it may be removed after the kiln is fired. The English kilns are generally 13 ft. long, 10 ft. wide, and 12 ft. high, which size contains and burns 20,000 bricks at once. Wood is the usual fuel used in these kilns, and they are frequently built with partitions, for containing the fuel and for supporting the bricks, in the form of arches, as will be presently described. The bricks must be placed in the kiln with great care, and this operation is called *setting* the kiln, and is performed by one or two men who understand the business, and to whom the raw bricks are delivered in barrows. The form of the setting is pretty nearly the same in the country kilns and in the London *clamps*, except that in the latter the arches are much smaller, because wood is only used for kindling and not for burning.

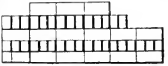
The bottom of the kiln, Fig. 1340, is laid in regular rows, of two or three bricks wide, with an

1340.



interval of two bricks between each, and these rows are so many walls extending lengthwise of the kiln, and running quite through it; they are built at least six or eight courses high, so as to give the kiln the appearance shown in the figure, which is an end view of the kiln. And this is permanent work, in kilns that have fire-places built in their floors, or it has to be formed every time the kiln is set, when it has a flat bottom. The intervals between the walls are laid first with shavings, or brushwood, or anything that will kindle easily, then with larger brushwood cut into short lengths, that it may pack in a compact manner; and lastly, with logs of split wood. This done, the over-spanning or formation of the arches is commenced; for this purpose every course of bricks is made to extend 1½ in. beyond the course immediately below it, for five courses in height, taking care to *skintle* well behind, that is, to back up, or fill up with bricks against the over-spanners. An equal number of courses, on the opposite side of the arch, is then set as before, and thus the arch is formed, which is called rounding, and is a nice and important operation, for if the arch fails or falls in, the fire may be extinguished, or many of the bricks above the arch may be broken. The intermediate spaces between the arches are now filled up, so as to bring the whole surface to a level, and then the setting of the kilns proceeds with regularity until it obtains its full height. In setting the kiln, not only in its body, but in the arches also, the ends of the bricks touch each other, but narrow spaces must be left between the sides of every brick for the fire to play through, and this is done by placing the bricks on their edges, and following what is called by brick-makers the rule of three upon three, reversing the direction of each course, as shown in Fig. 1341. The kiln being filled, the top course is laid with flat bricks, so disposed that one brick covers part of three others; which process is called *platting.*

1341.



Indian Kiln.—There are various methods in practice in India of filling and firing a kiln of the same construction as the above.

1st. Laying alternate complete layers of wood fuel and of bricks, the flues passing only 5 or

6 ft. into the interior of the kiln, all the rest of the floor being occupied by the first layer of fuel.

2nd. Arranging the bricks in a second set of flues five or six courses above the first, and crossing them at right angles; and so on with flues alternately in these two different directions to the top; or,

3rd. Having, as before, one series of flues at bottom, and above alternate complete layers of bricks and fuel.

Firing.—The kiln being filled, the *firing* succeeds, and this is a most delicate operation, and one that requires much experience. The fuel is kindled under the arches, and requires close watching and attendance, for being in a large body, it would burn violently and produce a sudden heat such as would crack and spoil the lowest bricks. To check the burning, the arch holes or mouths are closed with dry bricks, or even smeared with wet clay, in order to prevent the entrance of air and the rapid combustion that would ensue. The fire must be made to smother rather than burn, as in making charcoal, in order that by its gentle heat it may evaporate the humidity that remains in the bricks, and produce drying rather than burning. This slow fire requires to be kept up about three days and three nights, by occasionally opening the vents to supply air and additional fuel, and closing them until the fire *gets up*, as the workmen call it, that is to say, until it has found its way through all the chinks and openings between the bricks, and begins to heat those at the top of the kiln. To ascertain the progress of the fire, the top of the kiln must be watched, and as soon as the smoke changes colour from a light to a dark hue, the drying is complete, and the fire may be urged. The first, or white smoke, called water-smoke, is in fact little else but the steam of the water while evaporating, and when that is gone, the real smoke of the fuel succeeds. Now the vents may be opened to admit full draught, and a strong fire kept up for from forty-eight to sixty hours; but the heat must not be white or so strong as to melt or vitrify the bricks, and whenever it appears to be increasing too rapidly, the vent must be partly closed. By this time the kiln, if it contains thirty-five courses, will be found to have sunk about 9 in.; but the stronger the clay the more it will shrink, and it is by this sinking that the workman knows when the kiln is sufficiently burnt. The experience of burning a few kilns will show how much the clay of that particular place yields to the firing. When it is thus ascertained that the kiln is ready, the vent-holes, and all other chinks through which air can enter, are carefully stopped with bricks and clay. In this state it remains until the bricks are cold enough to be taken down, when they are distributed for use.

From the nature of the above process it will be evident that bricks of very different qualities must be found in the same kiln; for as the fire is all applied below, the lower bricks in its immediate vicinity will be burnt to great hardness, or perhaps vitrified; those in the middle will be well burnt; and those at the top, which are not only most distant from the fire, but more exposed to the open air, will be too little burned; consequently, if they can be used, they must be reserved for inside work that is not exposed to the weather, or they will soon fail and crumble to pieces.

English Clamp.—In the English method of open *clamp* burning, without any kiln, the piling and disposition of the bricks is the same as above described, except that the bottom arches are much smaller, as they are only intended to contain brushwood to produce the first kindling, and not for the future supply of fuel. No fuel is used except the *breeze* cinders and small coal, and this is distributed, by means of a sieve with wires about half an inch apart, over every course, as it is laid near the bottom, and over every alternate course, or every third course higher up in the kiln. The first layers of this fuel are from 1 in. to 1½ in. in thickness; but they diminish as they ascend, because the action of the heat is to ascend; consequently, there is not the same necessity for fuel in the upper as in the lower part of the kiln. The brushwood in the bottom ignites the lower stratum of fuel, and from the nature of its distribution the vertical as well as horizontal joints will be filled with it, and thus the fire gradually spreads itself upwards, and the whole clamp is nothing but a mass of bricks and burning fuel. The heat is therefore much more generally distributed throughout the whole mass, and in order to confine it, the entire outside of the clamp is thickly plastered with wet clay and sand, the bottom holes being opened or shut, as occasion may require, for regulating the draught of air.

Notwithstanding the heat is much more equally distributed throughout this form of kiln, yet the outside bricks all around receive very little advantage from the fire, and are never burnt; but being on the outside they are easily removed, and are reserved for the outside casing of the next clamp that may be built; and being then turned with their unbaked sides inwards, some of them become available. On taking down the clamp, the bricks are assorted into three separate parcels or varieties, according to their perfection and goodness. Those that are burnt very hard and have not lost their figure or shape, may be selected for arches. The main body of well-burnt bricks are called *stocks*, and those which are imperfectly burned are called *place* bricks.

These several varieties of brick have each a separate price, the best being worth twice as much as the worst. If the fire has not been carefully attended to, and has been permitted to get too violent, some of the lower bricks will become distorted by partial fusion, and may fuse and adhere together, when they are called *clinkers*, and are useless for building purposes, but form an excellent road material.

A coal clamp of 100,000 bricks rarely burns out under a month. There is a great saving of fuel in burning large clamps; but where time is an object, small clamps ought to be made. The bricks ought not to be opened out before they are thoroughly cool, as they are apt to crack by the breeze playing upon them when hot. The amount of coal to be used depends upon the quality of the fuel, and the degree of hardness to which it is wished to burn the bricks. Six hundred and fifty or seven hundred maunds of moderately good coal ought to be sufficient to burn 100,000 bricks; a great deal, however, depends also upon the clay; a light sandy clay, such as is found by river sides, takes less fuel than a hard, strong clay.

A maund is an Indian weight, varying in different localities from 24 to about 82 lbs. avoirdupois.

The Madras maund is 24 or 25 lbs.; the Bombay maund 28 lbs.; the Surat maund 41 lbs.; and the bazaar maund 82½ lbs.

In London, close instead of open clamps are employed, no spaces being left between the bricks. Each brick contains in itself the fuel necessary for its vitrification; the breeze or cinders serving only to ignite the lower tiers of bricks, from which the heat gradually spreads over the whole clamp.

Indian Clamp.—The native clamp, or *pajáwah*, is an arrangement for brick-burning in the open air, somewhat resembling the English *clamp*. The bricks and fuel are laid alternately, the former in courses of four or five bricks, the latter of 2 or 2½ ft. in thickness, the proportion of fuel being diminished towards the top. The whole is generally built with one side abrupt and nearly vertical, and with a long slope on the other. The fuel consists of dry grass, wooden chips, *khât* (manure), *koorah* (litter, miscellaneous dry sweepings), and *oopla* (dried cow-dung), and very generally a layer of wood under all.

The form of the *pajáwah* is generally triangular; its floor smooth and sloping at an angle of 15°, being lowest at the angle, where it is lighted. The upper surface slopes at an angle of about 30°, in the direction of its length.

The following is a note on brick-burning in *pajáwahs*, by Lieut. J. Finn, formerly Executive Officer of Materials at Roorkee:—The quantity of fuel used in the Hindoostanee kilns at and near Roorkee is about 6 in. thicker than the layer of bricks placed over it; that is to say, if the fuel is 3 ft. in thickness, the layer of bricks placed on the top of it should be 2½ ft. or five bricks high; each brick being 6 in. wide. A kiln now being filled at Roorkee has a layer of wood about 1 ft. deep all along the bottom, but none in the second or third tiers, excepting a small quantity at the mouth of the kiln to ensure its speedy ignition. When the kiln is ready for firing, about 1 ft. in thickness of fuel is spread all over its top, and over that 1 ft. of ashes.

The under-mentioned quantity of fuel will burn one lakh of bricks in a native kiln, namely, 325 2-bullock cart loads of *khât*, 750 maunds of *oopla*, and 100 maunds of fire-wood.

Once a kiln is filled, covered over on the top with ashes, and fired, it is not liable to injury from high strong wind; nor will a heavy fall of rain harm a kiln when in the above-mentioned state.

The size of bricks used in masonry works of the Northern Division, Ganges Canal, is 12 × 6 × 2½ in.

The sooner a Hindoostanee kiln is fired the better. When about one-third filled, the kiln ought to be lighted, for the fire will burn quicker and more equably before the fuel becomes compressed and partly decayed than it would otherwise.

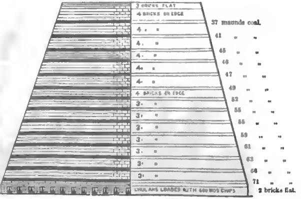
The fuel used in a *pajáwah* consists of all kinds of combustible refuse of towns and villages, and *oopla* and dung made into cakes well dried in the sun. *Oopla* and *huddy khuddy* (bones and pigs' dung) have been weighed before being put into kiln; of the former, from 1500 to 1800 maunds; of the latter, from 300 to 600 maunds; and about 6000 maunds of *koorah* (village refuse) are required for one lakh of bricks. Small quantities of wood have sometimes been put into kilns, but it proved disadvantageous, and the use of wood and *koorah* conjointly is injurious.

The time occupied in loading a kiln varies from two to three months for each lakh. Experience has convinced brick-makers in India that the sooner a kiln is fired the better. The rule is that when 40,000 or 50,000 bricks were piled into the kiln, it should be lighted; the progress of the fire being slow, any number of bricks can be piled afterwards.

Figs. 1342 to 1344 show sections of a brick clamp as burnt by Captain Sage. Contents of kiln, Fig. 1342:—Small wood and chips, 600 maunds; coal in layers, 750 maunds; bricks, 206,000. Contents of kiln, Fig. 1343:—75,000 bricks; 1185 maunds of wood.

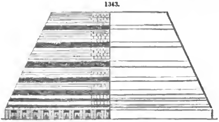
1342.

Burnt with coal at Bhoorsoot.



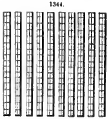
Ground Plan similar to that of Fig. 1343.

1343.



Burnt with wood at Jalspoor.

1344.



Plan of Chulahs.

Various experiments were made in Bengal, and the result published by the Military Board, in 1827 and 1828, on the burning bricks in *clamps*, both with wood and coal. The clamps were built with flues as described in the English *kilns*, but smaller, and filled with well-dried chips or brushwood. For the fuel above the flues, green wood was preferred, as retarding the fire; wood-loaded kilns generally burning too rapidly, and causing great loss by vitrifying the bricks in the centre. The wood was split up into pieces not exceeding 4 or 5 in. in thickness, and so arranged as to leave level surfaces, for the layers of bricks to be laid upon. The flues were 2 ft. high and 9 in. wide, with three bricks laid flat on them, having narrow intervals to allow of the fire ascending from the flues. The clamps were finished with alternate layers of brick and fuel, the bricks being laid touching each other throughout, the interstices formed by their contraction under the great heat being sufficient to ensure the firing of the upper layers of fuel. The sides of the clamp were then built up with mud and broken bricks, well plastered with mud to exclude the air.

Besides the advantage of cheapness, coal is shown to be in many other respects superior, as fuel, to wood; the space occupied by it between the layers of brick is so much smaller, that the clamp sinks much less, and its outer casing is less deranged. The wind which interferes with the gradual and equable process of the fire is thus better kept out. The loss by breakage is likewise much less, and the bricks from being burnt more slowly are more compact. The coal should be broken into pieces not exceeding 1 in. in diameter. In kilns, likewise, coal must have like advantages over wood except as regards the greater displacement of the casing of the clamps; the permanent walls of kilns not being liable to this contingency. Kiln walls may be built of bricks plastered with mud, and repaired with the same material from time to time; they should slope on the outside about 1 ft. in 5.

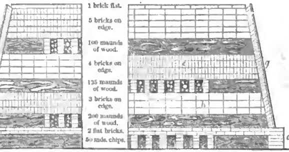
Another construction, by Capt. Bell, Figs. 1345, 1346, seems well adapted to prevent the sinking of kilns when wood is used as fuel.[1] The wood is everywhere contained in flues, crossing each other at right angles, the walls of which are supported by layers of bricks on edge, completely covering the area of the kiln.

The ground layer of four flat bricks being laid with equidistant flues, they are filled up with light wood and dry chips, over which two bricks are laid flat; on this is formed a second set of flues, running across the ground flues, and, after filling up between the flues with wood, the whole area is built over with three bricks on edge, the length of the bricks running in the same direction with the flues and wood. The full height is formed by an alternation of flues and solid masses of bricks, as shown in Fig. 1346. Two rows of bricks laid flat seem to be requisite above *each* set of flues, to prevent the bricks on edge from falling into them, whilst the fuel is being consumed.

To close the clamp, extend the flue opening as at *a*, Fig. 1345, one brick in length, and cover

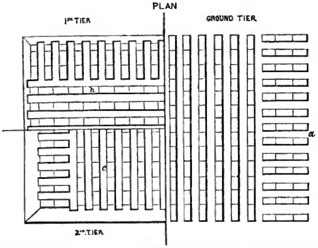
1345.

Brick Clamp burnt by Captain Bell at Burdwan.



Cross-Section. Longitudinal Section.

1346.



it with two flat bricks. Then build up, with one brick breadth-ways, the outer coating as at *g* (with half-dried bricks, or any kind), over which straw (well wetted) is laid on the slope from the top downwards, giving it a good coat of mud plaster. The mud should not be thickly laid on, but well rubbed into the grass. If thick, the heat of the fire and sun makes it peel off and admit the air, before the fire has gone through the kiln.

One great error appears to consist in putting large masses of wood into the *upper* tier flues: it is thus that so much material becomes vitrified. The ground flues ought to be filled (but not choked) with good dry fuel intermixed with chips, so as to communicate quickly through the whole. The wood of the first tier should be reasonably large, with some small pieces or chips; and in every higher tier in succession they should be less in size as well as in quantity; because, as all the fire and heat rise from below, the higher tier has the advantage of all the foregoing fine fires in addition to its own. Previous to its ignition, too many bricks should not be piled above wood, however great the quantity of the latter, or they will be irregularly burnt and much fuel wasted.

See Bond. Bond-Course. Brickwork. Construction. Kiln. Stone, *Artificial*.

Works and Papers relating to Brick-making:—Brughat, 'L'Art du Briquetier,' 2 vols., 1861. Dobson (E.), 'On Bricks and Tiles,' 1868. Medley (F. G.), 'Roorkee Treatise on Civil Engineering.' Papers by Clift, Fothergill, and others, in the 'Trans. Inst. Mechanical Engineers.'

BRICKWORK. Fr., *Maçonnerie de briques*; Ger., *Mauerarbeit, Ziegelwerk*; Ital., *Mattonato*; Span., *Enladrillado*.

A term used in the art of construction to denote the combination of bricks with mortar or cement.

Architects and surveyors in the neighbourhood of London adopt as their standard of measurement for brickwork the square rod of 272 ft. superficial, reduced to a thickness of $1\frac{1}{2}$ brick. In the provinces and by civil engineers the cubic yard is more commonly used.

A rod of reduced brickwork of four courses to the foot in height requires 4356 bricks, and a cubic yard requires 384 bricks. When the mortar-joints are limited to $\frac{1}{4}$ of an in. in thickness, the rod of brickwork contains 258 ft. cube of bricks and 48 ft. cube of mortar; the cubic yard contains $22\frac{3}{4}$ ft. cube of bricks and $4\frac{1}{4}$ ft. cube of mortar. When the joints are $\frac{3}{8}$ of an in. in thickness, the rod of brickwork contains 235 ft. cube of bricks and 71 ft. cube of mortar; the cubic yard contains $20\frac{3}{4}$ ft. cube of bricks and $6\frac{1}{4}$ ft. cube of mortar.

The proportions, in general, of bricks and mortar in any given quantity of brickwork vary according to the size of the bricks and the thickness of the mortar-joints. In practice, 3 cubic yards of mortar are allowed to a rod of brickwork, and 36 bushels of Roman cement with an equal quantity of sand; but when Portland cement is used there should be allowed about 38 bushels of cement to an equal quantity of sand. When the proportions of Portland cement to sand are to be as 1 to 2, 25 bushels of the former and 50 of the latter will be required for a rod of brickwork. 126 gallons of water are usually allowed to a rod of brickwork to slake the lime and mix the mortar. Cement requires rather more water, particularly Roman cement, which absorbs it very rapidly.

The weight of bricks varies considerably, some weighing only 5 lbs. and others $7\frac{1}{2}$ lbs., and in some cases as much as 9 lbs. each. For the purpose of calculation, however, the weight of a rod of brickwork just built may be taken at 16 tons, which will probably be reduced to 15 tons when the work becomes thoroughly dry.

Some bricks are very porous, and will absorb more than *one-fifth* of their weight of water, if immersed in it soon after their withdrawal from the kiln. When bricks are exposed to the rain,

which is usually the case when stacked for building, they take up a large quantity of water, which they never entirely part with. Ordinary London stocks absorb about *one-fifteenth* part of their weight of water in the process of building, most if not all of which they lose again by evaporation.

Brickwork built with Portland or Roman cement requires a weight of about 30 tons a superficial foot to produce fracture by compression; and when built with blue lias lime mortar, thoroughly set, it requires about 20 tons. When Portland cement is used, fracture almost invariably takes place in the bricks; but with Roman cement, particularly when used with much sand, fracture sometimes occurs in the cement itself, and still more frequently when mortar is the cementing material—a result naturally to be expected from a consideration of their relative degrees of strength. See CONSTRUCTION.

BRICK-NOGGING. FR., *Remplissage de briques d'un châssis de charpente;* GER., *Füllmauerwerk;* ITAL., *Muratura di riempimento.*

Brick-nogging or brick-nog partition, is a description of walling consisting of brickwork and timber. It is usually made of the width or thickness of a brick, and is framed similar to a wood partition, the quarters or studs being 2 or 3 ft. apart, with brickwork filled in between them: horizontal pieces, called *nogging-pieces,* are also laid in regular tiers between every two courses of bricks. Although brick-nogging does not add to the strength of a partition, it is some little security against fire.

BRICK-TRIMMER. FR., *Enchevêtrure de briques d'une cheminée;* GER., *Gurt bogen im Kamin;* ITAL., *Arco di mattoni.*

Brick-trimmer is the term applied to a brick arch abutting against the wood trimming just in front of a fire-place, and used to support the hearth. See Fig. 271, p. 121.

BRIDGE. FR., *Pont;* GER., *Brücke;* ITAL., *Ponte;* SPAN., *Puente.*

Bridges are structures, usually of wood, stone, brick, or iron, erected over rivers or other watercourses, or over ravines or railroads, to make continuous roadways between banks.

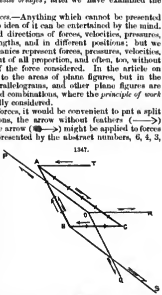
A *draw-bridge* is a bridge so constructed that a part of it may be temporarily removed, or drawn aside, to allow the passage of vessels; called also a *swing-bridge,* or *bascule-bridge,* when the part which opens turns *laterally* on a centre or end pivot. In mathematics and mechanics the terms *laterally, lateral,* and *laterality,* or the quality of having distinct sides are often misapplied. *Lateral,* as an adjective, signifies proceeding from, or attached to, the sides; as, the lateral branches of a tree; lateral shoots; or as an adjective this term may signify, directed to the side; as, the lateral view of an object. Sometimes, in mathematics, an equation of the first degree is designated as a *lateral equation.* In mechanics, *lateral pressure or stress* is a pressure or stress at right angles to the length, as of a beam or bridge; distinguished from *longitudinal pressure or stress.* And *lateral strength* is that strength which resists a tendency to fracture arising from lateral pressure.

In the sequel, we treat of the construction and mechanical requirements of *Draw, Girder, Lattice, Truss, Tubular, Flying, Suspension, Skew, and Trestle bridges;* after we have examined the nature and actions of pressures, thrusts, and tensions.

Equilibrium of Pressures, Thrusts, and Tensions;—Forces.—Anything which cannot be presented to the senses must be represented conventionally, or no idea of it can be entertained by the mind. We have no objection to represent the magnitudes and directions of forces, velocities, pressures, thrusts, and tensions by straight lines of different lengths, and in different positions; but we object to the careless manner in which writers on mechanics represent forces, pressures, velocities, &c., by straight lines, triangles, and parallelograms, out of all proportion, and often, too, without the least regard to the action, direction, or nature of the force considered. In the article on BOILERS, p. 425, we gave a conventional signification to the areas of plane figures, but in the present article the sides and angles of triangles, parallelograms, and other plane figures are employed to give an idea of mechanical operations and combinations, where the *principle of work* does not apply, as rest and not motion is here principally considered.

When comparing graphically the action of statical forces, it would be convenient to put a split arrow (↣) to designate the directions of tensions, the arrow without feathers (⟶) to point out the directions of thrusts, while the complete arrow (⟴) might be applied to forces in general. If three forces P, Q, R, Fig. 1347, be represented by the abstract numbers, 6, 4, 3, respectively, then if A B C be a triangle whose side A C = 6, A B = 4, B C = 3, equal parts taken from any scale of equal parts; let P O be a tension equal and parallel to A C, Q O a tension equal and parallel to A B, R O a tension equal and parallel to B C; these three tensions will keep the point O at rest. Three thrusts represented by three lines P O, O Q, O R, whose lengths are as 6, 4, and 3, respectively, and parallel to the sides of the triangle A B C, will also keep the point O at rest. Take A T equal and parallel to B C, then the two thrusts represented in magnitude and direction by the lines T A, B A, and the tension represented in magnitude and direction by the line A C, will keep the point A at rest. Again, if B S be equal and parallel to A C, tensions represented by A B, B S, and a thrust, C B, will keep the point B at rest.

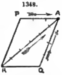
1347.



Let P A, Q R, Fig. 1348, be a parallelogram, if P A, Q A, represent the magnitudes and directions of two forces, two pressures, two thrusts, two tensions, or two velocities acting on the material point A; then the diagonal R A will represent the magnitude and direction of a single force, pressure, thrust, or tension, equivalent to the operations represented by the lengths and directions

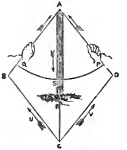
of P A and Q A. Such imaginary parallelograms form a great portion of the stock-in-trade of writers on mechanics. We have introduced Figs. 1347 to 1351 to illustrate the manner in which the different forms of arrows may be applied with advantage. The properties pointed out in Fig. 1347 depend upon the truth asserted of the parallelogram P A Q R, Fig. 1348, which we will prove presently.

1348.

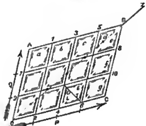


The principle of sufficient reason; first employed by Archimedes in demonstrating the fundamental propositions of mechanics.—Let P and Q, Fig. 1349, be two equal forces acting in the same plane on the rigid perpendicular prop A R, the point R fixed; further, let these forces P, Q, make equal angles, S A D, S A B, with the prop A R, which may turn to the right or left round the fixed point R. But as the forces P and Q and the angles B A S and D A S are also equal, there is no reason why the post A R will turn to the right or left; hence it will stand, and the two tensions will be neutralized by the perpendicular thrust of the post A R. This we call a mechanical demonstration, and the principle applied *the principle of sufficient reason*. For there is no reason why the post under consideration should fall to one side more than another, hence we conclude it will fall to neither side. Let A B C D be a parallelogram whose sides are all equal; if the length of the line A B be taken to represent the magnitude of the force Q, then A D will truly represent the force P; and two other equal forces, V and U, applied to the point C, represented in magnitude and direction by the lines C D, C B, will counteract the forces P and Q the same as the post A R, the diagonal A C being rigid. The principle of sufficient reason applies here as in the former case. It is evident that any number of equal forces may be applied in the directions of the arrows, P = Q = V = U, without disturbing the form of the equal-sided parallelogram A B C D, or the position of the rigid diagonal A. The abstract truth of the parallelogram of forces, thrusts, tensions, pressures, or velocities may be established by reasoning as follows: Let A B C O be a parallelogram; when its sides can be expressed by numbers, it may be divided into small parallelograms, the sides of which are all equal to one another. We have selected a very simple case, and taken O C = 4 equal parts and A O = 3 of the same parts. Let the force P be to the force Q as *m* to *n*; in the present example, P : Q :: 4 : 3.

1349.



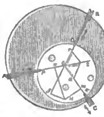
1350.



The forces P and Q applied to the material point O in the direction O C, O A, may evidently be represented by the lines O C, O A; if a new set of forces, represented by the small parallelograms, be introduced as represented by the arrows in the figure, the combined action of the forces P and Q will not be interfered with, nor will the equilibrium of the figure be disturbed. Take, for example, the small equal-sided parallelogram D E T L, and for a moment suppose the diagonal D T rigid; then *the principle of sufficient reason* applies to the forces introduced, and no disturbance takes place. Let us now view these forces under another aspect. The forces along the sides of the small parallelograms on the line C O are equal to the force P, but in a contrary direction, and hence destroys it. The forces represented on the line 9, 10, also destroy one another. This may be said of the forces on the line 7, 8; but the forces on the line A B are not neutralized, and are exactly equal to the force P, but applied to the point B in the diagonal O B. Again, the forces along the sides of the small parallelograms on the line A O are equal to the force Q, but in a contrary direction, and hence may be said to destroy it. The forces pointed out by the arrows on the line 1, 2, also neutralize one another; the same may be said of the forces supposed to be introduced on the line 3, 4, and so on, until we arrive at the forces pointed out on the last line B C, which, together, are exactly equal to the force Q, but applied to the point B in the diagonal O B. According as the equal parts be long or short, the point B will change its position; but it will always be in the diagonal O Z, and the forces $a + b + c + d$ = P and $g + f + e$ = Q will in all cases have their resultant position in the diagonal O Z. Had we supposed the force P to be divided into 1000 equal forces, O C would be represented by 1000 equal parts, and O A = Q would then be composed of 750 such parts, and our reasoning on the 750000 equilateral small parallelograms of forces would result in the same conclusion. The equilibrium of forces and pressures may be illustrated in a practical way by a simple mechanical contrivance, represented in Fig. 1351, easily constructed. Suppose P Q R to be a slate or board rolling freely upon three equal spherical balls placed on a horizontal table A B C. If any three points, P, Q, R, be taken in the surface of the plane movable on the balls, and cords, A P, B Q, C R, be attached, passing over the pulleys,

with a different amount of weight attached to the other ends—the ends with the weights attached are not represented in the cut—the board P Q R will roll upon the balls, and ultimately come to rest upon the table A B C, where the three forces destroy each other. When this experiment is carefully made, it will be found that the directions of the forces A P, B Q, C R, meet in the same point O. Again, from any scale of equal parts take O r = the pounds in the force drawing the cord Q B, and from the same scale of equal parts lay off O a = the pounds drawing the cord R C; then, if the parallelogram O $r s a$ be constructed, the diagonal O s will be in the direction of the third force acting over the pulley A. It will be further found that the units of length in O s, the diagonal, will = the weight or force acting by the cord A P.

1351.



If O a = 22 equal parts, O r = 28, and O s = 26, all measured on the same scale of equal parts, then, if 7 lbs. be attached to the cord Q B, and $5\frac{1}{2}$ lbs. to the cord R C, a weight of $6\frac{1}{2}$ lbs. must be attached to the cord A B to maintain this equilibrium. When forces are thus represented by a parallelogram, as O $r s a$, the forces represented by the sides are called the component forces, while the force represented by the diagonal is denominated the resultant. Another experiment may be instituted to determine the intensity of forces by this simple apparatus. Instead of three forces being applied to the board, let there be any number; and suppose H to be any point taken in the movable plane P Q R, and from H let fall perpendiculars H n, H m, H f, and so on, in the directions, or directions produced, of the forces; then the units of length, taken from any scale of equal parts, multiplied by the pounds in the corresponding force, will be what is termed the *moment* of that force tending to turn the board or movable plane upon the point H. This being done, the principle denominated *the principle of the equality of moments* may be verified by experiment. Here but three forces are applied, but any given number may be introduced; in the present case,

$$\text{H}\,f \times \text{B lbs.} + \text{H}\,m \times \text{C lbs.} = \text{H} \times n\ \text{A lbs.}$$

The student must not confound *the principle of the equality of moments*, just defined, with the intensity of forces usually considered by examining the motions they produce, or the spaces passed over when the motions are uniformly accelerated. It has been before shown that, generally,

$$(\text{Force}) = \frac{\text{W}}{g}\,\frac{v}{t}; \qquad [1]$$

t being an extremely small portion of time, denominated an element, during which the velocity v is generated. The above formula shows that if, by observing the laws of motion, we know for each instant the value of the ratio $\frac{v}{t}$, we shall then have that of the corresponding effort designated (Force) in the above formula. Suppose we know, from experiment, that the motion is uniformly accelerated, we have, for the space S, $\text{S} = \frac{1}{2}\,\text{V}_1 \times \text{T}^2$, in which

$$\text{V}_1 = \frac{\text{V}}{\text{T}} = \frac{v}{t}, \text{ as in [1];}$$

$$(\text{Force}) = \frac{\text{W}}{g}\,\frac{2\,\text{S}}{\text{T}^2}. \qquad [2]$$

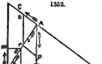
Suppose a locomotive weighing 10 tons (22400 lbs.) runs, with a uniform accelerated motion, a distance of 154·4 ft. in four seconds; required the force in lbs. capable of imparting this accelerated motion, the friction of the rail not being considered?

From [2] $(\text{Force}) = \frac{22400}{32\frac{1}{6}}\,\frac{2 \times (154 \cdot 4)}{4^2} = 13440$ lbs. (See pp. 93, 94, 116 Byrne's 'Essential Elements of Mechanics.')

Definition.—A bar is called a *strut*, or a *tie*, according as a thrust or a pull is exerted along its line of resistance.

Let C H B A, Fig. 1352, be a *skeleton diagram* representing centres and lines of resistances, H B a platform with a load W = 47 cwt. upon it, C B a chain supporting both load and platform; find, by construction, the tension of the chain and the amount and direction of the pressure upon H, the point about which the platform turns, the weight of which being neglected?

1352.



Draw W A perpendicular to H B, intersecting the chain in A; join A and H, and, from a scale of equal parts, lay off A p = 47, a part for each lb. in W, which acts in the direction A W. Draw $p\,r$ parallel to C B, and $r\,n$ parallel to A W; the parallelogram A $n\,r\,p$ gives the required tension and thrust. In the diagram A r = 37 equal parts, answering to 37 cwt., the pressure on the hinge H; A n = 26 equal parts, answering to 26 cwt., the pressure tending to break the chain. Take H s = A r, draw $s\,m$ parallel to W H, and $s\,t$ parallel to H C; then H t gives the thrust of W against the wall, which is represented by H C, and H m shows the pressure in the direction of the stationary wall H C.

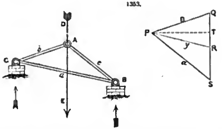
Given a triangular frame, A B C, Fig. 1353, loaded and supported both in the direction of the vertical line D E; find the relative proportions of the forces?

Put A, B, C, for the three joints, and a, b, c, for the three bars. These things being premised, from any point, P, draw P R, P Q, P S, parallel to the lines of resistance a, b, c, respectively; across these lines the vertical line Q R S, then the following proportions apply to the forces:—

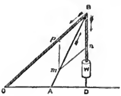
Load on A : supporting force at B : supporting force at C : stress along c : stress along a : stress along b; so stand in order and proportion the lines **Q S : S R : Q R : P S : P R : P Q.**

Out of the six proportions thus succinctly stated, to illustrate, we shall single out one: Load on A : supporting force at B :: Q S : S R.

1353.



1354.



Let a pole, A B, Fig. 1354, be supported by a cord, C B, and carry a weight, W; required the tension of the cord, and the pressure on the pole?

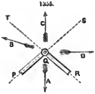
From B to *n* lay off equal parts, equal to the units of weight in W; draw *m n* parallel to C B, intersecting B A in *m*; draw *m p* parallel to B *n*; therefore the units in B *p* will give the tension of the cord C B, and the units, measured on the same scale of equal parts, in the diagonal B *m*, will give the thrust on the pole A B.

Struts may be distinguished from ties thus:—In Fig. 1355, P Q, Q R, represent two bars of a frame meeting at the joint Q; produce the lines of resistance beyond Q to S and T. Then a force in the direction of the arrow A, between the angle P Q R, both bars are struts; if the force be in the direction of the arrow B, in the angle T Q P, then P Q is a strut, and Q R a tie. Again, when the force is applied in the direction of the arrow C, both bars are ties; and, lastly, when the force is in the direction of the arrow D, in the angle S Q R, then P Q is a tie, and Q R is a strut.

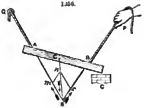
A beam, A B, Fig. 1356, resting on a wall, C, and supported by a cord, Q A; it is required to determine the direction and tension of the cord B P, so that the beam may not change its position when the wall C is removed, the point B being also given?

Let G be the centre of gravity of the beam, through which draw the vertical line G *s* in the direction of the plumb line, to meet Q A produced in *s*, join *s* B, and produce it; B P in the direction of *s* B shews the direction a cord fastened at B must take so that the beam will not change its position when the wall C is removed.

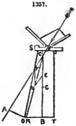
1355.



1356.

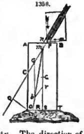


1357.



To find whether a pier, or other support, S T, Fig. 1357, will overturn by the action of a force P, or the resultant of several forces operating in a given direction, P C A. Produce the direction of the force P, and let fall the perpendicular O A; then, in order that the structure may not turn on the point O, we must have, G being the centre of gravity, weight of the structure S T × O B greater than P × O A. When (weight S T) × O B = P × O A, the pier will be on the point of turning on the edge, O.

1358.



By Construction.—Let B C be the vertical line passing through the centre of gravity of the pier or pillar, intersecting the direction of the force P in the point C; from a scale of equal parts take C F = the units in the pressure P, and from the same scale take C E = the units in the weight of the structure, S T; complete the parallelogram of forces, C D E F, then C D will give the amount and direction of the single force tending to overturn the structure or support, S T. When C D produced intersect the base within the edge O, the structure will stand; but should the point of intersection, R, fall without the base, the structure must fall.

A T, Fig. 1358, is a pier, or buttress, weighing 860000 lbs., P a pressure of 320000 lbs.; A B = O T = 6·6 ft.; O A = B T = 15 ft.; the cross-section A B T O is a rectangular parallelogram, of which G is the centre of gravity. The direction of the force P tending to overturn the structure cuts A B 4 ft. from A, and A O at C, 7 ft. from A.

It is required to find whether the structure will stand or fall, and what will be the amount of the pressure, P, just sufficient to overturn the solid mass of which A B T O is a cross-section?

$$C P = \sqrt{A C^2 + A P^2} = \sqrt{7^2 + 4^2} = 8 \cdot 0622577,$$
$$C P : P A :: C O : O Q,$$
$$\text{or, } 8 \cdot 0622577 : 4 :: 8 : 3 \cdot 969 = O Q.$$

Since A T is a rectangular parallelogram, a vertical line, S G m, passing through the centre of gravity, G, divides the base O T into two equal parts. ∴ O S = S T = 3·3 ft.; then we can compare moment of the wall = 860000 × O S = 2838000. Moment of the pressure = 320000 × O Q = 1270080; 2838000 being greater than 1270080, the structure will stand.

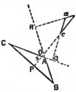
Putting x for the pressure that will just overturn it, acting in the direction of P, then,

$$x \times O Q = 2838000. \quad \therefore x = \frac{2838000}{3 \cdot 9069} = 715022 \text{ lbs.}$$

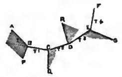
If P = 715022 lbs., the point R will coincide with the point O on the outer edge of the structure.

Geometrical Proposition.—If the sides, or the sides produced, of one triangle, a, b, c, Fig. 1359, be respectively perpendicular to the sides, or sides produced, of another, A B C, these triangles are similar. a Q, b P, b R, represent the three perpendiculars, angle C + C S P = a right angle, angle c + c S Q = a right angle; but angle C S P = angle c S Q, ∴ angle c = angle C.

1359.



1360.



In the same way the angle b may be shown to be equal to the angle B; and consequently the angle a = A.

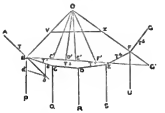
Funicular Polygon.—Funicular polygon is the term employed to designate a polygon formed of rods, chains, or cords, whose angular points are solicited by any forces whatever. The equilibrium of such a system of thrusts, tensions, &c., are subject to rules easily determined. First, let us suppose that the polygon has not all its sides in the same plane, and is represented by the contour, A B C D E F, Fig. 1360. Let P, Q, R, S, T, ... be the forces acting upon each of the summits A, B, C, D, E; the respective tensions of the sides A B, B C, C D, D E, E F, represented by T, T_1, T_2, T_3, ... respectively. If the entire polygon is in equilibrium, it must be so for all the summits separately, and since T_1 must be equal and opposite to the resultant of T and P, it follows that any two sides uniting at the same summit, and the direction of the force acting upon this summit, must be in the same plane; and the tension T_1 must be equal and opposite to the resultant of the force Q and tension T_2, and consequently in substituting at the summit C, for the tension T, its two components P and T, the forces P and Q, and the tensions T and T_2, supposed to be transferred to the point C, parallel to themselves, must be in equilibrium. We see also that the forces P, Q, R, and the tensions T and T_3, supposed to be transmitted to the summit D in parallel directions, must then produce an equilibrium. By continuing this process, we arrive at the conclusion, for the equilibrium of the funicular polygon, that when all the external forces and the tensions of the extreme sides are regarded as transferred parallel to themselves to any summit, they must necessarily produce an equilibrium there. These remarks are independent of the direction of the forces and the nature of the sides, and are applicable when the sides are subjected to efforts of compression instead of tension, with the reservation solely that the sides be sufficiently rigid to resist the compressions, without a change of form. Where the forces soliciting the funicular polygon are weights, in which case the forces P, Q, R, S, ... are all vertical and parallel, and the polygon necessarily in one plane; for, the direction of each force, and those of the two sides meeting at the summit, are in the same vertical plane; and, as through one side we can draw but one vertical plane, it follows that the two vertical planes, containing the same side of the polygon, are coincident, and so for the other sides. Again, since all the external forces P, Q, R, ... and the tensions T, T_4, of the first and last sides are in equilibrium, T and T_4 must also be in equilibrium with the single resultant of all the parallel forces.

Determination of the Tensions by a Graphical Construction.—If, in accordance with the preceding views, we describe upon the side A B, produced from any convenient scale of equal parts, a length equal to the tension T, and construct the parallelogram B a b d, Fig. 1361, the side B a, measured on the same scale of equal parts, will represent their tension, T_1 of the side B C, and the side B d, the external force P. Then, if we draw through the point B, for example, a line B G^1 perpendicular to the directions of the forces P, Q, R, ... upon which lay off B C^1, C^1 D^1, D^1 E^1, E^1 F^1, F^1 G^1, proportional to the forces P, Q, R, S, U, and from the same point erect the line B O perpendicular to A B with a length proportioned to the tension T, or to B b, the triangle B O C^1 having two sides, B O, B C^1, respectively perpendicular and proportional to the sides B b and B d of the triangle B b d, must be similar to it by the geometrical proposition preceding. Then the third side, O C^1, of the first will be proportional to the third side, b d or B a, or to the tension T_1, and will be perpendicular to the side B C of the polygon; the following triangle will be in the same condition, in relation to the side C D, to the force Q, and the tension T_2, which will be proportional to the side O D^1, and so on. Then, if the weight soliciting the different summits of the contour A, B, C, ... are in equilibrium, and we lay off upon a horizontal line lengths respectively proportional to these weights, and then from points of this line corresponding to each summit draw straight lines perpendicular to the directions of the sides of the polygon, all these right lines will intersect at the same point, and their lengths will be proportional to the tensions of the sides of the polygon, which will thus be determined. If a line V Z be drawn parallel to

B G¹, the triangle V O Z answers the same purpose as the triangle B O G¹. The triangle B O G¹, Fig. 1362, expresses the same relations as the triangle B O G¹, Fig. 1361, B G¹ being taken equal to the sum and in the direction of the forces P, Q, R, ... B O is drawn parallel to the direction of T, and B X parallel to the direction of T_1; G¹ X gives the tension of T, and G¹ O the tension of T_1, both measured on the same scale of equal parts as B G¹. O B is parallel to T or A B; O C¹ is drawn parallel to B C; O D¹ to C D; O E¹ to D E; O F¹ to E F.

We have been very particular to pass nothing over that might make the proper relations and actions of forces, thus circumstanced, clear to the mind of the student, since the proper arrangement of thrusts and tensions, the action of braces, struts, and ties, in bridge-building, roofing, and in all sorts of lattice-work, designed to combine strength with lightness, depend upon the extension of the simple principles here presented.

1361.



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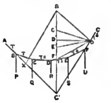
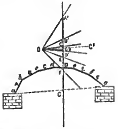


1363.



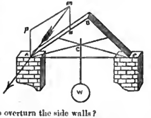
If the same Fig. 1362 be inverted, then such frame, Fig. 1363, consists chiefly of struts, and is, therefore, unstable unless their ends are made fast by suitable stays. In a polygonal frame loaded and suspended vertically, represented by the skeleton diagram, Fig. 1362, the bars which are struts in Fig. 1363 become ties, and the frame is stable and yet flexible.

The diagram of forces for Fig. 1363 may be constructed as follows:—Suppose the polygonal frame loaded vertically and supported vertically, let A, B, C, D, ... be the bars; *a*, *b*, *c*, *d*, ... the joints of which *b*, *c*, *d*, *e*, *f*, are loaded, *a* and *g* are supported. Take any convenient point, as O, draw O A¹ parallel to A; O B¹ parallel to B; O C¹ parallel to C; O D¹ parallel to D; O E¹ parallel to E; O F¹ parallel to F; and O G¹ parallel to G. Then draw the vertical line A¹ F¹ crossing the lines O A¹, O B¹, O C¹ . . . . Then if the whole load on the frame be represented by A¹ F¹, the parts into which A¹ F¹ is cut by the lines O A¹, O B¹, O C¹, ... will represent the fractional parts of the load that must rest on each of the joints to secure equilibrium.

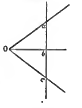
$A_1 B_1$ represents the part of the load to be applied at the joint *b*; $B_1 C_1$ the part to be applied at *c*; $C_1 D_1$ the part to be applied at *d*; and so on. The lengths of the lines O A_1, O B_1, O C_1, ... represent the resistances along the lines A, B, C, ... to which they are respectively parallel. The two parts $F_1 G_1$, $G_1 A_1$, into which $F_1 A_1$ is divided by the line O G_1 parallel to G represent the supporting forces at *a* and *g*, that is, $F_1 G_1$ represents the supporting force at *g*, and $G_1 A_1$ the supporting force at *a*. The horizontal stress of the frame is represented by the length of the perpendicular O G_1 let fall from O on $F_1 A_1$. If the angles of the polygonal figure A B C D . . . . be given, the angles of the diagram of forces O $A_1 F_1$ are also given; hence, when the length of any one of the lines in C $A_1 F_1$ is also given, the lengths of the other lines are readily found by plane trigonometry, to any required degree of accuracy.

If the skeleton diagram A B C D . . . . , Fig. 1363, represent an open frame, the bar G is omitted; in this case the stress along the outer bars, represented in the diagram of forces by the lines O A_1, O F_1, must be met by oblique forces as abutments; for vertical supports would not be sufficient. This frame, being, as before observed, composed of struts, is unstable, and must be connected with suitable stays.

1364.



1365.



Let A B and B C, Fig. 1364, be a roof resting on the side walls A and C; a uniform section of this roof weighs 6000 lbs., the angle B A C = 34°, B C A = 44°; it is required to find the thrust on the points A, C, the roof being without a tie-beam; what would be the tension of a tie-beam, A C, or of a rod connecting the feet of the rafters; and also find the direction and amount of the pressure of the roof to overturn the side walls?

To construct the diagram of forces, draw O *a*, Fig. 1365, parallel to A B; O *c* parallel to C B; and O *b* parallel to A C, Fig. 1364.

Draw the vertical line *a b c* = 6000 equal parts to represent 6000 lbs.

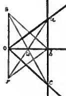
Let W = 6000 lbs. applied, suppose, at the centre of gravity, G, of the section.

∴ angle *a* O *b* = 34°; *b* O *c* = 44°. O *a b* = 90 − 34 = 56°; O *c b* = 90 − 44 = 46°.

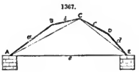
Sin. 78° : 6000 :: sin. 56° : O c = 5085·35. Natural sine of 78° = ·9781476; natural sine of 56° = ·8290376. Sin. 78° : 6000 :: sin. 46° : O a = 4411·44. Natural sine of 46° = ·7193398. ∴ The thrust on the point C = 5085 lbs., and the thrust on the point A = 4411 lbs. As sine of 90° : O a :: sin. a O b : $a\,b$ = 2466·8. ∴ $b\,c$ = 6000 − 2466·8 = 3533·2. ∴ The side wall at C supports 3533 lbs. of the weight W, and the side wall at A, 2467 lbs. nearly. As sin. 90° : O a :: cos. a O b : O b = 3657·3. ∴ The horizontal thrust along the side A C = 3657 lbs.

Draw A p perpendicular to A C, and = $a\,b$, the vertical weight at A, Fig. 1364; make A n = O a, the thrust along the rafter A B; complete the parallelogram A $p\,m\,n$, and draw the diagonal m A, = the amount and direction of the pressure of the roof tending to overturn the wall A. Or, to avoid complicating the figure, we reproduce the diagram of forces, Fig. 1366; taking the lines O a, $a\,b$, complete the parallelogram O $r\,b\,a$, then the diagonal $a\,r$ gives the amount and direction of the pressure as well as the parallelogram A $n\,m\,p$, Fig. 1364. On the lines O c, $c\,b$, construct the parallelogram O $s\,b\,c$, draw S c = the amount and direction of the pressure of the roof applied to overturn the wall C, when the tie A C is emitted.

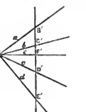
1366.



1367.



1368.



Given the skeleton diagram A B C D E, Fig. 1367, of a frame loaded and supported vertically; A E being horizontal. O B_1, Fig. 1368, is parallel to A B; O C_1 parallel to B C; O D_1 parallel to C D; O E_1 parallel to D E; and O F_1 is drawn parallel to A E; B_1 E_1 represents the whole load, and, being vertical, is perpendicular to O F_1. Now suppose the angle F_1 O C_1 = 12°, the natural tangent of which is ·21255 = F_1 C_1, when O F_1 = 1; the secant of this angle is 1·0223 = O C_1. F_1 O B_1 = 37°; F_1 O D_1 = 25°; F_1 O E_1 = 50°; then the comparative lengths of the lines in the diagram of forces will stand thus:—

	Tangent.		Secant.
O F_1 = 1;	$F_1\,C_1$ = ·21255	.. ..	O C_1 = 1·0223
	$F_1\,B_1$ = ·75355	.. ..	O B_1 = 1·2521
	$F_1\,D_1$ = ·46630	.. ..	O D_1 = 1·1033
	$F_1\,E_1$ = 1·1917	.. ..	O E_1 = 1·5557

The frame is vertically loaded with 5000 lbs; how is it distributed, and what are the particulars of its action when the forces balance each other?

$F_1\,B_1 + F_1\,E_1$ = 1·94525 = 5000 lbs.

1·94525 : 5000 :: 1·0223 : 2628 lbs. stress along the bar b or B C.
1·94525 : 5000 :: 1·2521 : 3218 lbs. stress along A B or bar a.
1·94525 : 5000 :: 1·1033 : 2836 lbs. stress along bar c.
1·94525 : 5000 :: 1·5557 : 3999 lbs. stress along d.

$F_1\,B_1 - F_1\,C_1 = C_1\,B_1$ = ·75355 − ·21255 = ·541; 1·94525 : 5000 :: ·541 : 1391 lbs. load on the joint B.

$F_1\,C_1 + F_1\,D_1 = C_1\,D_1$ = ·67885; 1·94525 : 5000 :: ·67885 : 1745 lbs. load on the joint C.

$F_1\,E_1 - F_1\,D_1$ = ·7254; 1·94525 : 5000 :: ·7254 : 1864 lbs. load on the joint D.

1·94525 : 5000 :: $F_1\,E_1$: 3063 lbs.,

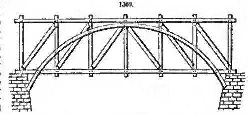
the vertical weight falling on the support at E, the remainder of the weight, or 5000 − 3063 = 1937 lbs., must fall on the support at A. The horizontal stress being represented in the diagram of forces by O F_1 = 1, we have 1·94525 : 5000 :: 1 : 2570 lbs., the horizontal stress of the frame. When the load is properly distributed, the necessary stays, C E, A C, require but little strength; without stays such a frame, however well balanced, would be unstable.

Examples of Bridges in which the actions of combined forces have been applied with more or less success.—The McCullum Inflexible Arched Truss Bridge approaches nearer the standard of perfection than any other wooden bridges that have fallen under the editor's notice; this fact is easily established by comparison and demonstration.

Fig. 1369 is what is known as the *Burr Bridge*. It is composed of lower and upper chords, and posts and braces. The posts are framed into the chords, and the braces are framed into the posts. Arches are placed on each side of the truss, securely fastened thereto, and, extending below the lower chords, abut against the masonry. This form of truss was extensively used throughout Europe and the United States previous to the introduction of railroads. Many spans were of great length, and in cases where the arches were large, and the masonry sufficiently permanent, this bridge was comparatively successful. Much difficulty was, however, experienced, by reason

of the absence of counter-braces. A moving load produced a vibratory and undulating motion, tending to loosen the connection of the timbers, which generally resulted in failure. Many of the *first* railroad bridges, both in Europe and America, were built upon this plan; but much greater difficulty was found in adapting it to the use of railroads than had been previously experienced in its use upon common roads. This difficulty arose from, first, the practical impossibility of perfectly combining the action of the *arch* and the *truss* (each system, of itself, being insufficient to carry the whole load); and, second, the absence of counter-braces. These defects, clearly apparent in their use on common roads, were greatly aggravated under the increased and concentrated nature of the

1369.



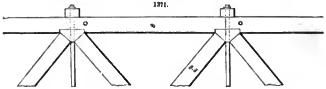
weight, and the rapid transit of trains on railroads. It is true they were obviated in part by adding largely to the amount of material in the structures; but as the difficulty was inherent in the plan, violent contortions in shape could not be prevented, and these in time caused failures. These remarks are intended to apply to spans of considerable length, as experience has proved that plans of even an inferior grade may be measurably successful in spans of ordinary length; whereas nothing short of the most judicious distribution of material will ensure permanency in cases where long spans are indispensable, and any arrangement which can be made permanent in the latter case must certainly prove so in the former. It is worthy of remark here, that this particular combination of the arch with the truss is even now, with some, a favourite idea, but it is believed that its warmest advocates will be generally found among those whose opportunities for practical investigations have been limited, and that it is only necessary that the question be properly presented to them, to produce a change of views in respect to it. This partiality for the combination of the arch and the truss is attributable partly to the fact that the simple truss has in many instances failed, and, as a last resort, the arch has been added, of such dimensions and strength as to be competent to carry the truss and load; the truss serving only as a stiffener to the arch, while the latter, thrusting upon the masonry, has sustained the whole weight. Besides, to the casual observer who has never studied bridge construction, this combination presents at least *an appearance* of great strength and solidity, which do not in fact exist. That the simple truss without the arch has failed in some instances is unquestionably true; but while many of these failures have been caused from inattention to, or ignorance of, the laws regulating the composition and resolution of forces, by far the greater number have arisen from the inferior quality, or lack of the requisite amount of material, or from inferior workmanship. The acknowledged failure of the *Burr Truss*, as applied to railroad purposes, led to the invention of several other plans, all of which were based upon the abandonment of the arch, and were aimed at perfecting a truss, which *of itself* would be sufficient to meet the emergencies of the case. This was in pursuance of what was considered a very reasonable hypothesis, namely, that *one* system properly proportioned must prove much superior to any method or arrangement in which the attempt was made to combine *two* distinct principles, in their nature heterogeneous. Among the most prominent plans presented to remedy existing defects was one invented by Stephen H. Long. This plan of bridge was composed of lower and upper chords, posts, and braces, similar in outline and general arrangements to the Burr Truss, but differing from it in detail. An efficient system of counter-braces was introduced; these were made adjustable by wooden wedges, as were also the sustaining braces, by means of which any desirable elevation or deflection might be given to the truss. This plan of truss was rigid to a degree not previously attained; and to such an extent was this true, that, when properly adjusted, no perceptible deflection was produced by the passage of the load. It was, however, found difficult to keep it in adjustment, in consequence of the great shrinkage of the wedges and other timbers of the truss.

The bridge from which this example, Figs. 1370 to 1373, of Long's framing is taken consists of seven equal openings of 180 ft., measuring from centre to centre of the piers. The bottom string course is a beam built of six planks, each a foot in depth, four of the planks being 5 in. in breadth; and the two outside planks each 4 in. When put together these planks form a beam 12 in. in depth and 28 in. in breadth. The planks are bolted together by screw bolts, placed about 2 ft. apart and alternately near the top and bottom of the beam, as shown in the vertical section, Fig. 1372. Short wedges of wood are let into the bottom string to the depth of about 1 in., and into the sides of these wedges are mortised the ends of the diagonal braces, Fig. 1371. These diagonal braces abut against similar wedges which are let into the top string beam. The top string consists of three lines of 8 in. square timber, placed with a small space between each, so as to make the whole breadth of the beam 28 in., the same as that of the lower string. The pieces composing this beam are bolted together at intervals of 7 ft. All the braces are 8 in. square, and the number of braces abutting on each block, both at the top and bottom string courses, is always three, arranged two on one side and one on the other. Along the top string beam are fixed short cross pieces, 5 in. by 7 in., one above each of the abutting wedges. These cross pieces receive the tops of the vertical ties, which pass entirely through the framing from top to bottom, and are secured above the top string and below the bottom one by screw-bolts and nuts. Similar cross pieces below the lower string receive the extremities of the vertical ties. Two of these vertical ties pass through each of the abutting wedges, so that for the two sides of the bridge there are four vertical ties in each length of 7 ft. The frames are connected at the top by cross beams, and

the lateral stiffness of the bridge is further increased by wrought-iron ties at each of the piers, these ties being carried into the masonry at some depth below the platform of the roadway. The longitudinal sleepers for the railway, which has only a single track over this bridge, are laid upon transverse beams, which rest upon the bottom string pieces and are placed one on each side of each of the abutting wedges throughout the whole length of the bridge. The platform is further strengthened by diagonal horizontal beams framed between the bottom strings, Fig. 1373.

1370.

1371.



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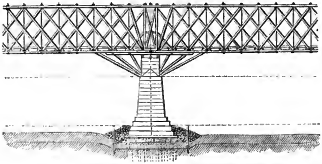

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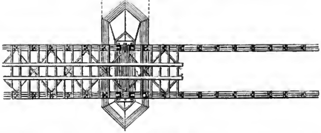
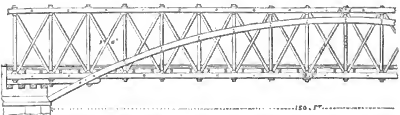


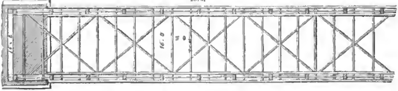
The invention of what is known as the *Howe Bridge* followed. In this, as in Col. Long's bridge, the idea of combining the arch with the truss was *originally* abandoned for reasons heretofore given, and it was believed that this simple form of truss would prove equal to any reasonable requirement. In the *Howe Bridge*, the posts used in the Burr and Long bridges are dispensed with, and iron rods substituted, by means of which any desirable *camber* may be given to the truss, thus overcoming the practical difficulty previously experienced in the adjustment of Col. Long's bridge, by the use of wooden wedges. This method of producing *camber* is certainly an improvement upon the means adopted in the Long Bridge for that purpose, but is much inferior to the latter in its method of counter-bracing, in that they are not adjustable, and perform a *negative* rather than a *positive* duty.

The Improved Burr Truss, introduced by Thomas Steele, is shown in elevation, Fig. 1374; Fig. 1375 is part of the plan of the same; and Figs. 1376, 1377, the detail to a larger scale of the tension-posts, braces, and counter-braces, upper and lower chords, and their iron fastenings.

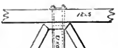
1374.



1375.



1376.



1377.

In this method of combining an arch with a trussed frame the arches are connected with the tension-posts, and the posts with the chords by screw fastenings, as seen in Figs. 1376, 1377; and all is so arranged as to admit of changing the position of the arches relatively to the chords, or of drawing together the chords without changing the position of the arches, and thus regulating and distributing the strain over the different parts of the bridge at pleasure. This adjustment must take place once or twice in each year until the timber becomes perfectly seasoned; after which, in a well-constructed bridge, but little attention will be required. Plates of iron should in all cases be introduced between the abutting surfaces of the top chords and arches, and all possible care taken to prevent two pieces of timber from coming in contact, by which decay is hastened. Care should also be taken to obtain the curve of the parabola for the arches, as it is a curve of equilibrium and of greatest strength.

The parabola is the curve of equilibrium when no load is upon the bridge, and also when the load is uniform; but there can be no curve of equilibrium for the variable load of a passing train. Stiffness can be secured in this case only by an efficient system of counter-bracing. The Improved Burr Truss, of Steele, Fig. 1374, presents an example of one of the systems to produce the required stiffness.

Bridges constructed on this plan will be found to possess an unusual amount of strength for the quantity of material contained in them, and, if well built and protected, great durability.

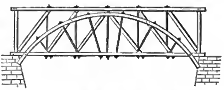
The following are the points to be attended to in erecting one of these bridges, as given by the inventor in Haupt's Treatise on Bridges:—The truss must first be raised, provided with suitable cast-iron skew-backs to receive the braces and tension-posts; and the several parts of the chords should be connected with cast-iron gibs. Wedging under the counter-braces must be avoided by extending the distance between the top skew-backs sufficiently to bring the tension-posts on the radii of the curve of camber of the bridge. The tension-posts must be about 8 in. shorter than the distance between the chords; and in screwing up the truss care must be taken not to bring their ends in contact with the chords; but they must be equidistant, and about 4 in. from them. When the truss is thus finished it must be thrown on its final bearings; and it is then ready to receive the arches which should be constructed on the curve of the parabola, with the ordinates so calculated as to be measured along the central line of the tension-posts. They must be firmly fastened to the posts and bottom chords by means of strong screw-bolts and connecting-plates, as shown at *d d*, and should abut on the masonry some distance below the truss, which can be effected with safety, as the attachment to the posts and chords will relieve the masonry of much of their horizontal thrust. When a bridge thus constructed is put into use, it will be found that, as the timber becomes seasoned, the weight will be gradually thrown upon the arches, which will ultimately bear an undue portion of the load. To avoid this, the camber must be restored and the posts moved up, so as again to divide the strain between the truss and the arches.

The *Howe Bridge* is composed of lower and upper chords, braces, and counter-braces, vertical rods, and cast-iron *bearing-blocks*. The braces abut on the *bearing-blocks*, which pass through the chords in such a manner as to permit the rods to bear directly upon them. Spans of considerable length were built upon this plan, but experience proved that even this truss—like all others—had its limit, beyond which it could not be safely extended.

In the progress of railroad enterprises, in order to save large expenditures of money for masonry, longer spans than had been previously used became desirable, and in certain locations absolutely indispensable; besides this, locomotives were largely increased in weight, to meet the demands of traffic, and furnish a more economical mode of working; and thus arose the necessity for the adoption of some other expedient to meet the increased requirements of bridges. As all had been done by way of improving this truss that mechanical skill could devise, and which an extensive practice had amply afforded, it became evident that some *radical* change must be made in its arrangement, to enable it to meet the exigencies of the case. In this emergency the *arch*, heretofore condemned in the *Burr Truss*, was again resorted to; for it had been proved, from the experience which its use in that truss had afforded, that an *arch* of sufficient size, abutting against permanent masonry, would place the truss in a position of secondary importance.

It will be observed that the arch of the Burr Bridge, Fig. 1369, abuts upon the masonry in precisely the same manner as the arch of what is denominated the *Improved Howe Truss*, Fig. 1378, and the difference between the two consists simply in the mode of connection with the truss, and not in any change of principle or method of action.

1378.



It will be seen that the Burr Arch is securely fastened to the posts and braces of the truss, forming a solid adjustable mass. In Fig. 1378 the arches are not fastened to the braces or rods, but have an independent connection with the lower chord of the truss, by means of rods radiating from the former to the latter. By this method it was supposed that any desirable adjustment could be effected, and that the strain could be put upon either system, or equally upon each.

This new arrangement, although plausible in theory, is found impossible in practice, for the following reasons:—

1st. The rods from the arch to the lower chord are of various lengths, consequently the contractions and expansions must vary proportionately.

2nd. Not a single rod in the arch is of the same length as those in the truss, hence the expansion and contraction of the rods in the truss will vary from that in each, and all the rods connecting the arch with the lower chord.

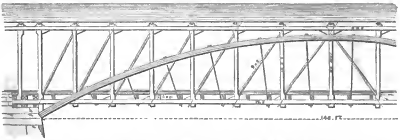
3rd. This combination is exceedingly liable to maltreatment from the careless or ignorant.

4th. And even if it were everything in practice that is claimed for it in theory (which is not the fact), it involves a constant expenditure for adjustment, which must continue during the existence of the bridge itself.

The Burr Truss, Fig. 1369, with all its defects, *can be made superior by far* to the *Improved Howe Truss*, Fig. 1378. For, in the former, there may sometimes be a yielding and compression between the parts of the truss and those of the arch, producing a certain degree of united action; while in the Howe Truss everything depends upon the length of the rods, which must always change with the temperature, and thus render an approach even to perfect adjustment a matter of extreme delicacy. But, in either Fig. 1369 or Fig. 1378, it is clearly evident that, in order to have a structure absolutely safe, the arch and the truss—each of itself, independently of the other—should be of sufficient strength to sustain the whole load, that the strain may be borne alternately by each separate system.

Fig. 1379 shows an elevation of a bridge erected upon Howe's plan over Sherman's Creek, on

1379.

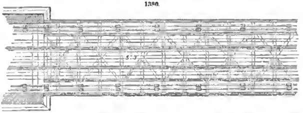


the Pennsylvania Central Railroad. Fig. 1380 is a plan, and Fig. 1381 a vertical section. The bridge has two spans, each 148 ft. 3 in. from end to end of the bow, or 154 ft. 6 in. from the

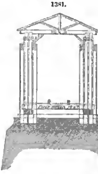
2 x 2

centre of the pier to the end of the truss. The pier is 3 ft. 2 in. wide at top and 6 ft. at the skew-backs. The truss is formed of three rows of top and bottom chords, and two sets of posts

1380.



1381.



and braces. It is counter-braced by rods of 1 in. iron between the braces. The panels increase in width from the end towards the middle of the span. The first panels are 9 ft. 1½ in. from centre to centre of posts, and the middle ones 12 ft. 1½ in.

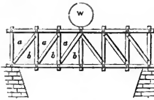
In order to simplify and make clear the real points of difference existing in the combinations of the various plans of trusses of the same general outline, it may be stated that the material composing *any bridge truss*, whether of wood or iron, or of both, is subjected either to *tension or thrust*, and it is upon the proper application of these elements, together with a judicious distribution of the material, rather than upon any difference in detail that the perfection of any bridge structure depends; this may be illustrated by reference to Figs. 1382 to 1385.

Fig. 1382 is the truss of the Burr Bridge; in this the upper chord and braces are acted upon by thrust, and the lower chord and posts by tension.

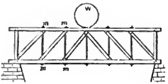
Fig. 1383 is the Howe Truss, without the counter-braces; in this also the upper chord and braces are subjected to thrust, and the lower chord and vertical rods are acted upon by tension.

Fig. 1384 is a plan of truss sometimes used, the counter-rods being omitted; in this the upper chord and vertical struts are subjected to thrusts, and the lower chords and diagonal rods are acted upon by tension.

1382.



1383.



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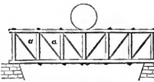

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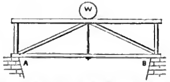


Upon a comparison of these plans it will be discovered that the variations between the Burr Truss, Fig. 1382, and the Howe Truss, Fig. 1383, consist in the use of vertical rods and bearing-blocks in the latter, instead of vertical posts in the former, both having precisely the same duty to perform. It will also be seen that Fig. 1384 varies from Fig. 1383, in that the rods are placed diagonally instead of vertically, changing the element of thrust from the diagonal braces in the latter to the vertical struts in the former, and transferring the element of tension from the vertical to the diagonal line.

Much importance is sometimes attached to just such modifications in detail as exist in Figs. 1382 to 1384, *while the nature and intensity of the destroying forces are the same and equal in each*. This has been proved by actual experiment, by the celebrated engineer and bridge-builder, D. C. McCallum, as follows:—Models were built, one on each plan, of equal length and height of trusses, containing the same sectional area and kind of material in chords and braces, and of equal perfection in details and workmanship, when it was found that the real difference in strength was unappreciable; and it may be well to add, that any given amount placed upon each, in progress of the experiments, presented precisely the same characteristics and contortions in shape, until final failure took place. All bridges having their chords parallel, irrespective of the particular method adopted in combining them, and regardless of the amount of material used in their construction,

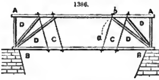
when loaded to nearly the point of fracture, present somewhat the same appearance, the greatest deflection *being invariably* at points near the abutments. This will be understood by the statement, that the vertical strain is increased, as the distance from the centre, to the ends of the truss; at the centre the vertical strain is nothing, and at each end of the truss it is equal to one-half the weight of the structure and its load.

In point of strength, the arrangements, Figs. 1382 to 1381, are not superior to the simple combination, Fig. 1385.

All bridges having their chords parallel exhibit the same uniformity of action, and may be illustrated by reference to Fig. 1386, in which A A is the upper chord; B B, the lower chord; C C, tension-rods; D D, braces.

When a sufficient weight is applied to any truss of this outline, to cause deflection below the straight line, the upper ends of the braces, D D, are made to approach each other, and the distance between the ends is diminished; and as the deflection increases, the upper ends of the braces, D D, will describe arcs, *a b*, of a circle *downwards*, the radius of which being the length of the braces, D D. But when the upper chord is arched, as in Fig. 1387, a sufficient weight will cause the braces, D D, to describe an arc *upwards*, represented by *c d*, Fig. 1387. When the chord, *c e*, becomes straight, the arc will then be described downwards, as shown in Fig. 1386. As an illustration of the McCallum *Inflexible Arched Truss*, see Fig. 1388, in which A A is the lower chord; B B, the upper chord; C C, tension-rods; D D, braces; E E, struts; and W, weight.

1386.



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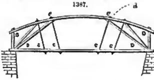

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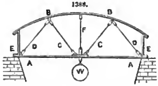
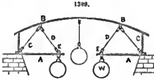


1389.



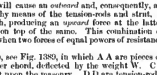
Upon an inspection of this figure, it will be seen that any deflection produced upon the centre of the arch, by means of the weight W, will cause the points B B to separate, by thrusting *outward*, and in the direction of the ends of the truss, producing an *upward* movement of the upper chord, at the ends of the braces D D, the latter describing arcs of a circle *upward*, and from thence will be communicated, by means of the tension-rods C C, to the centre of the lower chord, raising the latter at the point where the rods, C C, meet. By removing the weight W, and inserting a vertical strut at F, the upward movement of the chords will be arrested by the weight W. This peculiar action may be described as follows:—

Any deflection produced in the centre of the arch will cause an *outward* and, consequently, an *upward* force at the upper ends of the braces, which, by means of the tension-rods and strut, is transferred directly back to the under-side of the arch, producing an *upward* force at the latter point, equal to the original *downward* force applied on top of the same. This combination of forces is in agreement with a well-known law, namely, when two forces of equal powers of resistance are opposed to each other, a state of rest is produced.

For a further illustration of the action of this truss, see Fig. 1389, in which A A are pieces of the lower chord, the centre being removed; B B, upper chord, deflected by the weight W. C C are braces which pass through the lower chord and rest upon the masonry. D D are tension-rods. It will be seen that the ends of the pieces of the lower chord at E E are raised considerably above a horizontal line. This upward tendency will continue until the upper chord between B B is deflected below a straight line, when the action will be reversed.

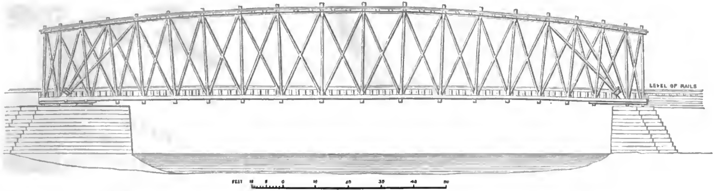
Fig. 1390 exhibits the forces at a state of rest, in which A A are portions of the lower chord; B B, upper chord; C C, arch-braces, which pass through the lower chord, and rest in the masonry; D D, tension-rods; E E, braces; W, weight. It will be seen that the strain produced by the weight W is transferred to the lower chord by means of thrust upon the braces E E, to the points F F, and, by means of tension on the rods D D, to the points B B, and from thence it is brought upon the arch-braces C C, which rest upon the masonry. In this manner a perfect equilibrium of forces is effected, as it is evident that the point G cannot change position, unless the points B B are thrust *outward* towards the ends of the truss, which must raise these points, this being prevented by the strain upon the points F F, communicated by the weight W, through the braces E E.

1390.



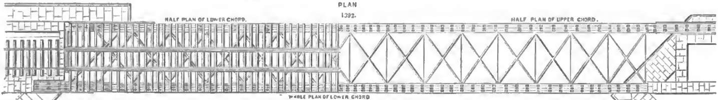
For a full plan of McCallum's Inflexible Arched Truss the reader is referred to Figs. 1391 to 1395. Upon inspection, it will be observed that the sustaining principle is very much increased

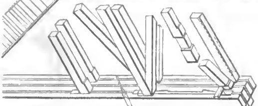
1391.



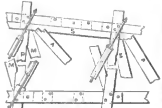
PLAN

1392.

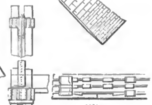




1393.



1394.



1395.

toward the ends of the truss, not only by the addition to the amount of material at these points, but it will be seen also that the panels become shorter as the vertical strain increases. The posts are placed upon lines radiating with the arch; the braces form equal angles with the posts; and in this way the latter are made to approach more nearly together toward the ends of the truss. The student has already had sufficient evidence of the great strength of this form of truss, and it has also been shown that the tensile strain upon the lower chord is much less than in any other known plan. In fact, the latter may be *entirely severed*, and the structure will still be competent to sustain a heavy load. In this, it differs from all other combinations.

In Fig. 1394, U is the upper chord; S, straining beam; A, arch-brace; M, main-brace; C, counter-brace.

Upon referring to Fig. 1391, which represents a clear span of 180 feet, it will be seen that the arch-braces which rest upon the abutments are extended to points on the arch about 47 ft. from the abutments. From the top of each set of arch-braces, running diagonally on each side of the truss, are placed heavy suspension-rods, which are connected with the lower chords 12 ft. farther from the masonry. Thus the bridge seat is substantially transferred to a point 47 ft. towards the centre of the bridge, reducing a span of 180 to 86 ft., so far as the *tensile strain* upon the lower chord is concerned. For this intermediate space of 86 ft., the arch-beam is of sufficient strength to sustain the whole load, if required. *Strength*, however, is not all that is required, for a railroad bridge especially, subject as it is to a *moving* load; there must also be *rigidity, stiffness*, and freedom from vibration. A bridge *may* be strong yet flexible, rigid yet weak; in fact, flexibility is incompatible with durability; the structure should be prepared at all times to receive its load, and should not be permitted to change shape in the slightest degree by its passage over it. To produce this result, an effective system of counter-braces is indispensable.

The proper office of counter-braces is frequently misunderstood, as is evident from the manner of their application in many cases in which they are used as *check-braces only*, having a *negative* rather than a *positive* action; this may be readily shown. When the load is applied, the truss is deflected in consequence of the yielding of the braces; this has the effect of *shortening* the diagonals in the direction of their length, while the diagonals in the direction of the counter-braces are correspondingly *lengthened*; this will leave a space between the ends of the latter, and the *bearing-block* in the lower chord. When the truss is in this condition, if wedges are inserted between the ends of the counter-braces and the lower chord, in such a manner as to fill up the whole space, it is evident that the weight may be removed without at all affecting the shape of the truss, the deflection originally produced by the weight being maintained by the counter-braces, the strain upon the sustaining braces and other portions of the truss remaining precisely the same as when the weight was suspended.

Now suppose the original weight to have been 200 tons, it is evident that, as soon as it is removed, each counter-brace will be subjected to an upward thrust, easily found from its position; the sum of all the thrusts making 200 tons. Now let there be a smaller load applied, this load will not produce any additional strain upon any portion of the truss, nor will the deflection be increased in the slightest degree; the only effect produced by suspending the latter weight will be the relief of the counter-braces, equal to the difference between the first and second weights.

The inventor has found it very difficult to explain this clearly in the course of conversation with some individuals, from the fact that *weight* and *strain* were confounded. Now it is true, when the original weight was applied of 200 tons, the abutments were loaded with just 200 tons more than previously, and the truss was also loaded with 10 tons more; but when the wedges were driven, and the weight removed, while the abutments were relieved of 200 tons pressure, the truss still retained the original strain produced, the weight being required to *produce the strain*, the latter remaining after the former has been removed.

In order to make a practical application of the above, the following method of adjusting the *Inflexible Arched Truss* is submitted. When these bridges are raised, it is usual to load them with a train of locomotive engines, attached closely to each other, and that greater weight may be obtained, the tenders are sometimes detached, and the bridge covered with engines only; with this load, the latter is strained down to a perfect bearing in all its parts; by this means the whole structure is more or less deflected, while the counter-braces are hanging loosely in their places; if, therefore, when the bridge is in this condition with its load, the counter-braces could be lengthened with considerable force, it would not recover its original shape upon removal of the load, but would be held down by the action of the counter-braces to very nearly the same position as when loaded. In this plan of bridge, the lower ends of the counter-braces rest in *iron stirrups*, which are attached to the vertical ties or posts at a point near the lower chord by means of castings and nuts, by which they may be lengthened several inches; in this manner they are made to perform a *positive* duty. When the bridge is adjusted as above, it is clear that a *less* load than that originally applied cannot produce any deflection whatever; the only effect of the passage of a train over it will be to relieve the counter-braces, and will not add a pound pressure upon any timber of the trusses.

In the arrangement of any bridge truss the attainment of the following requisites is desirable:—

1st. Such equilibrium of forces as will produce uniformity of action.

2nd. Such quantity and distribution of material as will ensure *a large surplus* of sustaining principle, *thereby guarding the structure against accident*.

3rd. *Perfect rigidity*, that the combination in all its parts may have permanency *equal to the durability of the material composing the same*.

4th. The arrangement of the parts should be such as to be free, if possible, from *the necessity of adjustment*.

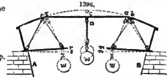
The McCallum *Inflexible Arched Truss* meets all these requirements.

Problem.—Let it be required to find the equal weights w, w, Fig. 1396, kept in a state of rest by a single weight, W, which has caused the arc q C a to assume the chord p D b, the rigidity of

the arc being neglected. Let R = the radius of the arc q C a, and put $2c$ = its length; then the chord $q\,a$ and versine C D are readily calculated. Let the chord $q\,a = 2\,d$, and $\text{C D} = 2\,e$. Let $f = \text{A}\,q = \text{A}\,p = \text{B}\,a = \text{B}\,b$ and $g = \text{B}\,n = \text{B}\,m = \text{A}\,s = \text{A}\,r$. Also let $\text{A B} = 2\,h$

$\frac{2\,h - 2\,d}{2} = h - d$, $\frac{h - a}{f} = \cos.\,\theta$, putting θ for the angle $a\,\text{B}\,n = q\,\text{A}\,s$.

1396.



$$\frac{2\,h - 2\,c}{2} = h - c,\ 2\,h - 2\,c = \text{A B} - p\,b.$$

$\therefore$ Putting ϕ for the angle $b\,\text{B}\,n = p\,\text{A}\,s$, $\frac{h - c}{f} = \cos.\,\phi$.

$$\therefore \phi - \theta = \text{angle } a\,\text{B}\,b = n\,\text{B}\,m = s\,\text{A}\,r.$$
$$\therefore m\,n = g \sin.\,(\phi - \theta).$$

Then, according to the principle of work, $2\,g \sin.\,(\phi - \theta)\,w = 2\,e\,\text{W}$. $\therefore w = \frac{e\,\text{W}}{g \sin.\,(\phi - \theta)}$.

Let $\text{A B} = 2\,h = 188$ ft.; the length of the arc q C a = the straight line p D b = 2 C = 136 ft.; R = 200 ft.; $m\,\text{B} = g = 60$ ft.; $b\,\text{B} = f = 50$ ft.

It will be found that the arc q C a before being disturbed contains 38° 57′ 40″; the versine of this arc = 11·449 ft. = $2\,e$; the chord = 133·39576 ft. = $2\,d$.

$$\frac{h - d}{f} = \cdot 5460424 = \cos.\,56^\circ\,54'\,15'';\ (\theta). \quad \frac{h - c}{f} = \cdot 5200000 = \cos.\,58^\circ\,40'\,4'';\ (\phi).$$
$$\therefore \phi - \theta = 1^\circ\,45'\,49''.$$
$$\therefore \frac{e}{g \sin.\,(\phi - \theta)} = \frac{5 \cdot 7245}{60 \sin.\,(1^\circ\,45'\,49'')} = 3 \cdot 100092. \quad \therefore w = \text{more than 3 times W}.$$

Consequently, the weight W before reducing the arc q C a to the straight line p D b must raise more than six times its own weight if posited at s and n.

Description of an Iron Bridge, in which the Forces are well combined to meet the demands of Railway Traffic.—The bridge we now propose to describe is one belonging to a system of bridge-building introduced by Wendel Bollman; it was erected at Harper's Ferry, U.S., the practical working of which was carefully observed by the editor of the present work. This iron suspension trussed bridge was 124 ft. between the abutments. The length of the cast iron in the stretcher was 128 ft. The weight of the cast iron, 65,137 lbs.; weight of wrought iron, 33,527 lbs.; making the total weight of cast and wrought iron, 98,664 lbs.

Fig. 1398 is an elevation of part of the side, showing one pier and part of the cast-iron stretcher. The cap is removed from the pier to show how the rods are secured.

Fig. 1397 is an elevation of both piers and of the eight panels of which the bridge is composed. The system of arranging the braces and connecting-rods is exhibited in this figure.

Fig. 1401 is a cross-section, showing the floor-bracing and the position of the rails. Fig. 1401 also shows, in section, the roof and posts.

Fig. 1400 shows a plan of the flooring of the bridge, the positions of the rails, and floor-bracing.

Fig. 1399 shows two posts, part of the stretcher, and the diagonal rods in one of the panels.

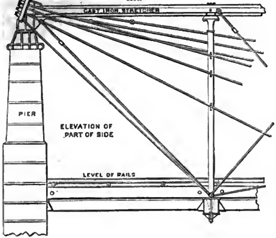
The wrought iron requires little workmanship, the rods from the centre to abutments having but an eye at one and a screw at the other end; with a weld or two between, according to length. The long counter-rods have two knuckles and one swivel for adjustment of strain, and convenience in welding, as well as in raising the whole.

The cast-iron stretcher is octagonal without, circular within, and averages 1 in. of metal. It is cast in lengths according to the length of panel, and jointed in the simplest manner,—at one end of each length is a tenon, at the other a socket. The latter is bored out, and the tenon and its shoulder turned off in a lathe to fit the socket; thus, when thoroughly joined, to form one continuous pipe between abutments. The ends of the sections of cylinders, inserted into those contiguous, are slightly rounded, to allow a small angular movement without risk of joint fracture. A cast-iron plate or washer sets on a bracket cast with each abutment end of stretcher, and at right angles to the centre acting-rods. The tension-bars are passed through this washer to receive a screw-nut for the erection and adjustment of the system. The stretcher or straining beam, the vertical posts, and suspension-bars, compose the essential features of the bridge; each post being hung by two bars from both ends of the stretcher independently of all the others; and each post and pair of tension-bars forming with the stretcher a separate truss. This system, perfect in itself, is additionally connected by diagonal rods in each panel; also by light hollow castings, acting as struts. The diagonal side rods might be safely dispensed with; for the peculiar merit of the truss is its perfect independence of such provision. They are therefore used as a safeguard only in case of the fracture of any of the principal suspension-rods.

By this combination of cast and wrought iron, the former is in a state of compression, the latter in that of tension; the proper condition of the two metals. It unites the principles of the Suspension and of the Truss bridges. *Each* bar performs its own part in supporting the load in proportion to its distance from the abutment; so that the entire series of suspending-rods transmits the same tension to the points of support as would be equally transmitted from thence to the centre of the bridge.

This bridge, it will be seen, is composed of seven independent trusses, which transfer the weight concentrated on each floor beam directly to the abutments, without aid from any other connection; and not from panel to panel, as in general use. The strain on cast and wrought iron is wholly in direct line; and the result, the least quantity of metal is required to carry a given weight. The weight of bridge and load has a vertical pressure on the piers, towers, &c., the only horizontal thrust being from the expansion of iron, which may be accommodated by rollers, sliding on an abutment bracket placed over the pedestal, or by other means: the necessary dimensions of masonry therefore become moderate.

1398.



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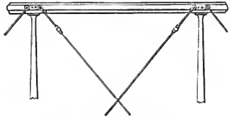

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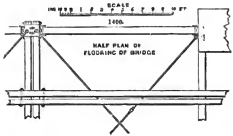

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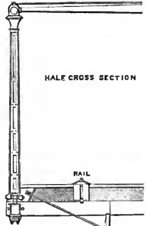

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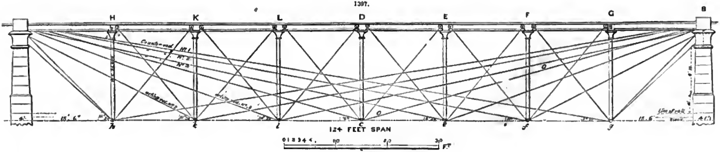


It is evident, from an inspection of the cuts, that no chord is requisite at the bottom of the truss to resist tension; the only advantage of that employed is to regulate the movement produced by expansion, in the performance of which agency the resistance is one to compression. Although the abutment-bracket casting and its pedestal were so constructed as to admit of accommodation to expansion, by rollers, yet such contrivance was omitted with the view of fully testing the effect of greatest expansion throughout the system.

This bridge was inspected by the writer, ten months after it was erected at Harper's Ferry; during which time it had been exposed to extremes of cold and heat, and to an average run of twenty trains daily. From the closest inspection, we find that the extreme expansion measures, as near as possible, $\frac{7}{16}$ in. on each tower, or $\frac{7}{8}$ in. in the entire length, 128 ft. of stretcher; and without the slightest perceptible derangement of masonry; the dimensions of which are 4 ft. square of base, 12 ft. high, and 2 ft. 9 in. at top.

While on the subject of expansion, it may be well to notice the effect from difference in expansion of the rods. At the first point of suspension, or where the longest and shortest rods meet, the counter-rod is about four and a half times longer than the acting-rod; and the expansion of the counter is four and a half times that of the acting-rod. But there is also a proportionate difference in the lengths of stretcher from the point directly over the centre of connection to the extremities of these rods. This has been practically proved in this bridge. The suspender bolt, when the expansion is extreme or $\frac{7}{8}$ in. in length of stretcher, exhibits a motive difference of $\frac{3}{16}$ in. toward the short or acting rod; which difference is provided for, as seen by slot, dotted in elevation, where the vertical suspender bolt moves to accommodate any such difference, and to give that proportion of weight to each rod according to the angle. It affords easy access for repairs; for instance, should a new floor beam be required, it is but needed to slacken the horizontal rod and the keys in longitudinal strut, remove the washer under point of suspension, and let down the beam to be replaced: which can be done without trestling up any part of the bridge. In case of fire, the floor may be entirely consumed without any injury to the side truss.

The permanent principle in bridge-building, sustained throughout this mode of structure, and in which there is such gain in competition with every other, namely, the direct transfer of weight to the abutments, renders the calculation simple, the expense certain, and facilitates the erection of secure, economical, and durable structures.

Details.—Resistance of cast-iron stretcher G H to compression, 177,511 lbs., or 4930 lbs. the sq. in. Half weight of bridge and load: weight of iron, 24,000 lbs.; weight of wood, 15,000 lbs.; weight of load, 184,000 lbs.; momentum, 25,000 lbs. = 248,000 lbs..

Size of Acting-rods.

No. 1 section of iron 2·46 = 2 bars $1\frac{1}{2} \times \frac{7}{8}$ | No. 3 section of iron 3·97 = 2 bars 2 × 1
No. 2 „ „ 3·31 = 2 „ $1\frac{5}{8} \times 1$ | No. 4 „ „ 4·31 = 2 „ $2\frac{1}{8} \times 1$

Strain on Acting-rods.

$$A\,h;\quad \text{No. 1, } \frac{26761\cdot 8 \times 25}{17} = 39355 \text{ lbs. strain.}$$

$$A\,k;\quad \text{No. 2, } \frac{23007\cdot 8 \times 38}{17\cdot 5} = 49674 \text{ lbs. „}$$

$$A\,l;\quad \text{No. 3, } \frac{19254\cdot 1 \times 52}{18} = 55623 \text{ lbs. „}$$

$$\text{No. 4, } \frac{15500 \times 67}{18\cdot 5} = 56136 \text{ lbs. „}$$

Weight on Acting-rods.

No. 1, 31,000 − 4,238·2 = 26,761·8.
„ 2, 31,000 − 7,992·2 = 23,007·8.
„ 3, 31,000 − 11,745·9 = 19,254·1.

Value of Iron in Acting-rods.

No. 1, { 16,000 the sq. in.; 2 rods 7 in. diameter, length 23 ft. 2 in.
2 bars $\frac{7}{8} \times 1\frac{1}{8}$ in. diameter, 25 ft. 3 in. length.
No. 2, 15,000 the sq. in.; 2 bars 7 in. × $1\frac{5}{8}$ in. diameter, 38 ft. length.
No. 3, 14,000 the sq. in.; 2 bars 7 in. × 2 in., length 52 ft. 5 in.

Size of Counter-rods.

A g; No. 1 section of iron 2·5 = 2 bars $1\frac{5}{8} \times \frac{3}{4}$.
A f; No. 2 „ „ 3·9 = 2 „ 2 × 1.
A e; No. 3 „ „ 4·5 = 2 „ $2\frac{1}{4} \times 1$.

Strain on Counter-rods.

$$\text{No. 1, } \frac{4238\cdot 2 \times 112}{18\cdot 5} = 25712 \text{ lbs. strain.}$$

$$\text{No. 2, } \frac{7992\cdot 2 \times 97}{18} = 43069 \text{ lbs. „}$$

$$\text{No. 3, } \frac{11745\cdot 9 \times 82}{17\cdot 5} = 55037 \text{ lbs. „}$$

Weight on Counter-rods.

$$\text{No. 1, } \frac{31000 \times 17\cdot 5}{128} = 4238\cdot 2.$$

$$\text{No. 2, } \frac{31000 \times 33}{128} = 7992\cdot 2.$$

$$\text{No. 3, } \frac{31000 \times 48\cdot 5}{128} = 11745\cdot 9.$$

Value of Iron in Counter-rods.

No. 1, 10,000 the sq. in.; 2 bars $1 \times 1\frac{3}{4}$, length 112 ft. 7 in.
No. 2, 11,000 the sq. in.; 2 bars 1×2, „ 97 ft. 4 in.
No. 3, 12,000 the sq. in.; 2 bars $1 \times 2\frac{1}{4}$, „ 82 ft. $1\frac{1}{2}$ in.

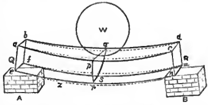
Value of iron in counter-rod *o*, 13,000 the sq. in.; 2 bars $1 \times 2\frac{1}{4}$, length 66 ft. 11 in. Length of posts, 15 ft.; diameter of posts, 6 in.; weight on each post, $\frac{218000}{8} = 31000$ lbs. Diagonal braces, 1 in. diameter, 22 ft. 9 in. in length.

Trial made on the 1st day of June, 1852, *to prove the Capability of this Bridge.*—Three first-class tonnage engines, with three tenders, were first carefully weighed, and then run upon the bridge, at the same time nearly covering its whole length, and weighing in the aggregate 273,550 lbs., or $136\frac{1}{2}\frac{275}{1000}$ tons nett, being over a ton for each foot in length of the bridge. This burden was tried at about eight miles an hour, and the deflections, according to gauges properly set and reliable in their action, were at centre post $1\frac{3}{8}''$, and at the first post from abutment $\frac{9}{16}$ of an in. From this test it is found that the load did not cover the entire length of bridge by about 13 ft., yet the excess of weight in the middle, and at a speed of about eight miles an hour, produced no greater deflection than $1\frac{3}{8}$ of an in. at the centre post, and $\frac{9}{16}$ of an in. at the first point from abutment.

Before proceeding farther, it is necessary to point out some serious mistakes made by experimenters and writers on the strength of materials. When discussing the strength of girders resting on supports, the editor of the present work, in his new theory of the strength of materials, first pointed out fallacies involved through introducing an imaginary line, termed the neutral axis, and merely investigating the upright laminæ of the material. We do not propose to discuss this subject thoroughly here, but to show how errors may be involved when the strength of girders is considered with respect to forces supposed to act only in parallel upright planes. See 'Civil Engineer and Architect's Journal,' June, 1846.

If a beam, Q R, Fig. 1402, rests loosely on two supports, A and B, and is loaded in the middle with a weight, W, which deflects it; before the weight is placed on the beam $ab = pq = cd$; and $ef = rs = nm$; but when the beam is deflected by W, pq is greater than ab or cd, and rs is less than either ef or mn. Before the beam is loaded it is supposed to be rectangular; in most cases this change of form may be detected by experiment. Although the nature of the material and amount of pressure may render this change of form imperceptible, yet these forces acting across the girder, in the directions of $p\,q\,r\,s$, are in operation, loosening bolts, buckling and puckering upright sheets, and so on. This action should be carefully attended to by engineers in constructing girders, whether solid, hollow, or composed of skeleton frames.

1402.



The material at rs is wire-drawn and compressed, while at pq the material becomes upset, extended, and loosened, according to the elastic limit and nature of the girder. The current erroneous theory of the strength of materials supposes, when the beam is bent by a weight, W, the fibres are compressed at pq and extended at rs, without alteration of breadth; that is, pq remains $= ab$ or cd, and also $= rs$ or ef. A portion of the body will often be forced out near the line pq; but when the substance supporting the weight is tough, the separation may take place irregularly and diagonally, with a sliding cutting motion, and not directly through the plane $p\,q\,r\,s$, in the middle.

Stone Bridges.—The art of constructing stone bridges has always been and still is as much the domain of practice as of theory. The long and intricate calculations which it is necessary to go through in determining the principal dimensions of a stone bridge, though these calculations are always, with a wise precaution, subordinated to practice; the little time which those upon whom the guidance of engineering works devolves have to devote to the calculations, and the dispatch with which projects have to be designed and executed; and other considerations affecting skilful builders who, for want of time or opportunity, have failed to gain sufficient theoretical knowledge, the absence of which might be compensated for by their long practice aided by a few simple and precise principles—all this has induced Edmond Roy, the experienced French engineer, to compress into a few pages some practical information and formulæ, into which enter only the simplest elements of arithmetic and geometry, and by means of which may be readily determined the dimensions of aqueducts, bridges, viaducts, and retaining walls.

Before proceeding further, we give this practical epitome of Roy: it speaks for itself.

Empirical Formulæ serving to determine the Principal Dimensions of Bridges in Masonry of Semicircular, Elliptical, Segmental, and Gothic Forms.

Depth of Masonry at the Crown and Form of the Curve of the Intrados.—Up to the present time the greater number of empirical formulæ giving the depth of masonry at the crown determine this depth in consideration of the span alone. In this way a bridge having a semicircular or an elliptical arch, even if the latter be depressed to the degree of $\frac{1}{10}$, ought, in accordance with these formulæ, to possess an equal depth at the crown. Such are the formulæ of Perronet, of Gauthey, and of Rondelet.

These formulæ appear to us defective; in proof of which we might point out the great difference

which exists between the dimensions of the masterpieces of the celebrated Perronet and those which they would have had if his formula had been applied.

In determining the thickness at the crown, we ought evidently to take into consideration:—

1. The span of the arch.
2. The degree of depression.

The greatest radius of the curve of the intrados and the magnitude of the arc of the intrados alone corresponding with these two conditions, the depth at the crown in segmental bridges must be determined by the former of these two quantities or by the two combined. It is also obvious that the lateral thrust upon the abutments with the depression given to the arch, and the dimensions of the abutments at the springing, will therefore be determined by the radii of the curves of the intrados. All other dimensions will follow, generally, from the depth at the crown.

Signification of the Letters employed in the Formulæ.

Q = the span of the arch.
R = the longest radius serving to determine the depth at the crown.
F = the rise, or distance between the level of the impost and the summit of the intrados.
C = the depth at the crown.

Semicircular Arches.

We have
$$R = \frac{Q}{2}; \qquad [1]$$
$$F = R = \frac{Q}{2}; \qquad [2]$$
$$\text{General values} \;.. \begin{cases} C = 0\cdot30 + 0\cdot07\,R; & [3] \\ C = 0\cdot30 + 0\cdot08. & [4] \end{cases}$$

Formula [3] is applied by us to any span, with ordinary materials.

Formula [4] is applicable to cases in which materials of feeble resistance are employed, such as certain kinds of freestone. The dimensions denoted by this formula are not excessive for spans of less than 12 or 15 mètres, and it may with propriety be employed.

Arches heavily banked.—In the case of arches supporting thick masses of embankment, it will be necessary to add to the depth at the crown in the proportion of 0·02 for each mètre of embankment above the extrados.

Elliptical Arches.—In the elliptical arch the radius of the upper segment, which is the longest radius, may, in accordance with the various conditions according to which we wish to construct the curve of the arch, have many dimensions for the same span and the same rise. We shall therefore, in order to have a uniform formula for elliptical arches, always consider as a basis of calculation that the curve is of 3 centres only, with segments of 60°. It will not, however, be necessary always to construct the curve of the intrados with 3 centres; it may be of 3, 5, 7, or 9, as may be deemed expedient; we have chosen 3 merely as a uniform basis of calculation. It is plain that a curve of 5, 7, or 9 centres, substituted for one of 3 which has served as a basis of calculation, must have the same rise as the latter. Our opinion is that the curve of 3 centres should never be employed, as it must of necessity be angular.

2. The mode of calculation which we have adopted fixes *a priori* the utmost limit of depression which it is proper to give to elliptical arches, and consequently indicates the moment when we should begin to employ the segment.

The general value of R in cases of curves with 3 centres, the arcs of which are of 60°, is
$$R = Q \times 1\cdot183 - 1\cdot366\,F. \qquad [5]$$

Let r represent the radius of the lesser arcs, then $r = Q - R$ [6]. If we make $F = 0\cdot134 \times Q$ or $\frac{Q}{7\cdot46}$, we have $R = Q \times 1\cdot183 - 1\cdot366 \times 0\cdot134 \times Q$; whence $R = Q \times 1$, and
$$r = Q - R = 0.$$

This result agrees with the geometrical principle, that the chord of an arc of 60° is equal to the radius.

Thus, according to our principles, the employment of arches of the elliptical form is limited between $F = \frac{1}{3}\,Q$ and $F = \frac{Q}{7\cdot46}$.

On the other hand, if we compare the section of the ellipse, Fig. 1407, which is depressed to $\frac{F}{Q} = 0\cdot20$ with the segment of 60° or $0\cdot134 \times Q = F$, drawn in a dotted line near it, we shall see that the aperture, or vent, which would result from the employment of each of these two curves would be the same, or nearly so; the difference will be still less on comparing the segment before mentioned with the curve of Fig. 1404. In this latter case it is indeed nothing. Practically, then, there would be no advantage whatever in employing an elliptical arch having a rise of less than $\frac{1}{5}$ of the span, because in such a case we should have a curve too much depressed at the summit, and because this ellipse might be advantageously replaced by a segment with a rise of $\frac{1}{7\cdot46}$ affording a vent equal to that of the ellipse.

In practice elliptical arches having a rise of less than $\frac{1}{5}$ of the span have never been employed.

General Values of the Elements serving to determine the depth at the crown of elliptical arches:—
$$R = 0 \times 1\cdot183 - 1\cdot366\,F;$$
$$C = 0\cdot30 + 0\cdot05\,R. \qquad [7]$$

Plan of Curves with several Centres.—Let A B, Fig. 1403, be the span of the arch, and I F the perpendicular on the middle of A B = the rise.

Describe the half-circumference A F″ B with ½ A B for a radius.

Divide the half-circumference A F″ B into as many equal parts as there are to be centres.

Produce the perpendicular I F as far as F″, the point where it cuts the half-circumference and divides the top segment into two equal parts.

Draw the chords B 1, 1 2, 2 F″, F″3, 3 4, 4 A. Take upon A B any two points *r*, at equal distances from the extremities A and B, which will be the centres of the first arc of the curve and the radius of which will be B *r*. Through the point *r* draw *r o* parallel to the radius 1 I, which will cut the chord B 1 in *o* and B *o*, and be the chord of the first arc. Through the point *o* draw *o p* parallel to the chord 1 2; through the point F draw F *p* parallel to the chord 2 F″: the point of intersection *p* of the latter two parallels will determine the chord *o p* of the second arc and the chord *p* F of the half arc of the summit. Through the point *p* drawing *p* R parallel to 1 2, which will cut in *r* the radius *o r* produced, and in R the perpendicular I F produced, the axis of the arch: the points *r′* and R will be the centres of the second arc and of the arc of the summit. Figs. 1404, 1405, give illustrations of curves with 7 centres. It will be seen that the construction is exactly the same; but the first two radii may be taken at pleasure, and the third, that of the arc of the summit, may be determined as for Fig. 1403, which is the case of a curve with 5 centres only.

It follows from the means which we have pointed out that it would be necessary to proceed cautiously, in order to give the proper dimensions to the smaller radii necessary to produce a regular and graceful curve approaching as near as possible to the ellipse. To avoid this we have drawn up Tables applicable to the describing of curves with 5 and 7 centres, and by means of which we may determine by a simple multiplication the length to be given to the first lesser radii of the curves.

There are only two distinct conditions according to which elliptical curves may be traced:—

1. Supposing that the angles in the centre of each of the arcs are equal to each other.
2. That the magnitudes of the arcs are equal.

We give Tables Nos. I. and II., which satisfy the former condition, and Nos. III. and IV., which satisfy the latter for curves with 5 and 7 centres.

Elliptical Arches of 5 and 7 Centres, equal Angled.

No. I. — No. II.

5 centres, Angles $= \frac{180^\circ}{5} = 36^\circ$. Proportions:		7 centres, Angles $= \frac{180^\circ}{7} = 25^\circ\ 43'$. Proportions:		
Of the Rise $\frac{F}{Q}$ to the Span	Of the 1st Radius $\frac{or}{Q}$ to the Span.	Of the Rise $\frac{F}{Q}$ to the Span.	Of the 1st Radius $\frac{or}{Q}$ to the Span.	Of the 2nd Radius $\frac{pr'}{Q}$ to the Span.
0·36	0·278	0·30	0·192	0·276
0·35	0·265	0·29	0·180	0·263
0·34	0·252	0·28	0·168	0·249
0·33	0·239	0·27	0·156	0·236
0·32	0·225	0·26	0·145	0·223
0·31	0·212	0·25	0·133	0·210
(1) 0·30	0·198	0·24	0·123	0·148
0·29	0·185	0·23	0·113	0·187
0·28	0·171	0·22	0·104	0·177
		0·21	0·095	0·166
		(2) 0·20	0·086	0·155

Elliptical Arches, with Arcs of nearly equal Magnitudes. 5 Centres.

No. III.

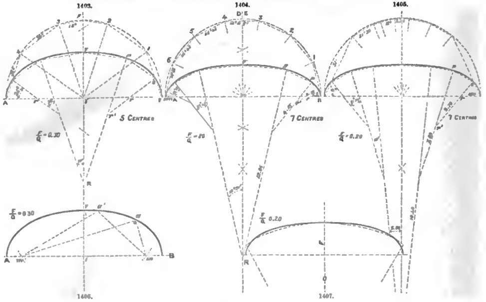
Proportions:		Angles:		
Of the Rise $\frac{F}{Q}$ to the Span.	Of the 1st Radius $\frac{or}{Q}$ to the Span.	Of the 1st Radius with the Horizontal Line of the Springing.	Of the 1st Radius with the 2nd.	Of the 2nd Radius with the Vertical.
		° ′	° ′	°
0·36	0·300	49 0	32 0	9
0·35	0·289	50 20	30 40	9
0·34	0·279	51 40	29 20	9
0·33	0·268	53 0	28 0	9
0·32	0·257	54 20	26 40	9
0·31	0·246	55 40	25 20	9
0·30	0·235	57 0	24 0	9
0·29	0·224	58 20	23 40	9
0·28	0·213	59 40	22 20	9

Elliptical Arches with Arcs of nearly equal Magnitudes. 7 Centres.

No. IV.

Proportions:			Angles:			
Of the Rise F to the Span Q.	Of the 1st Radius o r to the Span Q.	Of the 2nd Radius p r to the Span Q.	Of the 1st Radius with the Horizontal Line of the Springing.	Of the 1st Radius with the 2nd.	Of the 2nd Radius with the 3rd.	Of the 3rd Radius with the Vertical.
			° ′	° ′	° ′	° ′
0·30	0·220	0·431	44 53	22 37	10 30	6 0
0·29	0·210	0·425	45 30	22 30	16 0	0 0
0·28	0·200	0·419	46 7	22 22	15 30	6 0
0·27	0·190	0·413	46 45	22 15	15 0	6 0
0·26	0·180	0·406	47 23	22 7	14 30	6 0
0·25	0·170	0·400	48 0	22 0	14 0	6 0
0·24	0·160	0·394	48 37	21 53	13 30	6 0
0·23	0·150	0·388	49 14	21 46	13 0	0 0
0·22	0·140	0·382	49 51	21 39	12 30	6 0
0·21	0·130	0·376	50 28	21 32	12 0	6 0
(3) 0·20	0·120	0·370	51 0	21 30	12 0	5 30

Note.—The horizontal columns marked by the figures (1), (2), (3), correspond to the examples given in Figs. 1403 to 1405 .



The rise and span of an arch being given, divide the rise by the span; the quotient $\frac{F}{Q}$ will be one of the numbers of the first column on the left, or near it: the products of the span by the proportions corresponding to this quotient, situated on the same horizontal line, will give the length of the first radii. The radii near the summit of the curve must be determined from the diagram.

It is necessary to remark that in the application of Tables Nos. III. and IV., in which the angles in the centre are not equal to each other, the divisions of the half-circumference must be made according to the angles indicated in these Tables. See application, Fig. 1405.

The principles of our Tables have nothing absolute about them; they may be varied on the plan and the number of centres increased, if it be found that the limits are too restricted; for the construction employed for 5 and 7 centres is analogous to that to be employed for 9, 11, or 13 centres. Only the flatness of the curve at the summit is proportional to the increase in the number of centres, and greater care is needed in the construction of the plan. Our Tables are designed only to give, within practical limits, the means of avoiding the necessity of making

experiments, and of obtaining *a priori* the required curves. Our general formula [5] gives the values of the radii for a curve of 3 centres with angles in the centres equal.

We do not advise the adoption of the curve of 3 centres for a depression of less than 0·36, for in the two viaducts of Port-de-Piles and of Auzon (railway from Tours to Bordeaux), in the construction of which Roy took part, the former having three arches of 31 mètres, and the latter five arches of 20 mètres. The designs for elliptical arches of 3 centres with angles in the centres equal, gave a depression of 0·33. In the execution of these works, recourse was obliged to be had to curves of 5 centres, because with 3 centres only there was a very distinct angle at each change of curvature.

Tracing the Ellipsis.—1. Gardener's ellipsis.

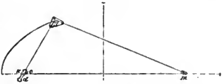
Let A B, Fig. 1406, be the span of the arch and major axis of the ellipsis. Upon the middle of A B raise the perpendicular I F equal to the rise of the arch, which will be half the minor axis of the ellipsis. From the point F, as a centre with ½ A B or I B as a radius, describe an arc cutting the line A B in two points, *m* and *m'*, which will be the foci of the ellipsis. If at the foci *m* and *m'* we fix the ends of a thread, the whole length of which is equal to A B, the major axis of the ellipsis, and with a style keeping the thread equally tense, we move it round from B to F and A, the style will trace a curve which will be an ellipsis, and the right lines *m a*, *m' a*; and *m a'*, *m' a'*, drawn from the points *a* and *a'* to the foci *m* and *m'*, are radii vectores, and they show the positions of the thread as the style moves round.

1. The line bisecting the angle formed by the two radii vectores from the same point in the ellipsis is a normal to the curve in this point. This property of the ellipsis will furnish us with a ready means of determining the joints of the voussoirs. We will return to this subject presently.

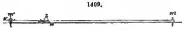
2. The plan of describing an ellipsis by means of a thread is applicable only to the laying out of gardens, from which its name is derived. For plans of arches where a very exact curve is required, we propose the following method:—

Substitute for the ordinary thread a piece of wire, the diameter of which should be from ½ to ¼ of a millimètre; at the foci *m* and *m'*, Figs. 1408, 1409, fix two pins, which will serve as points of rotation; one of these pins passes through a hole in the middle of a pair of pincers, closing with a screw, the use of which is to hold firmly one end of the wire; the other pin has a ring attached to it, to which the other end of the wire is fixed. The part *d* of the pincers is intended to balance the part *c*. Instead of pincers, the part *c* might have a small cylinder with a ratchet wheel. *m* is a small flat piece of board, mounted on three rollers turning on their centres; *b* is a horizontal pulley of 0·05 in. diameter turning on a vertical axis fixed in the board *m*; around this pulley passes the wire which guides the elliptic track that must be followed by the board *m*; through a hole in the board at *q* passes a style, loaded a little, if necessary, to render its trace upon the plan plainly visible. The board *m* must always be moved, so that the hole *q* is on the bisecting line of the angle formed by the radii vectores. The curve thus described will be yet more exact if the pin of the pulley be made hollow to enable the style to pass through it.

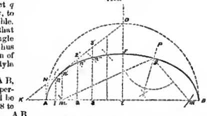
1408.



1409.



1410.



Tracing an Ellipsis through Points.—Let A B, Fig. 1410, = Q, *i* the middle of A B, and the perpendicular *i* F = F. The foci *m* and *m'* will be determined in the manner shown, Figs. 1408 to 1410. From the point *i* as a centre with A *i* or $\frac{A\,B}{2}$ as a radius, describe the part of the circle A D. At the point A, the extremity of the major axis, erect the perpendicular A N upon A B, equal to A *m'*, the distance from the focus to the extremity of the major axis. Joining the points D and N, the straight line D N produced will meet the major axis A B produced to a point K; the straight line D N possesses properties which form the basis of the method we are about to point out.

1. It will be a tangent to the ellipsis at the point where it is met by a perpendicular to the major axis, erected from the focus *m'*.

2. All the perpendiculars to A B, erected from any points between A and *i* and included between A B and D N, will be equal to the radius vector passing through the point in which the ellipsis would be met by each of these perpendiculars respectively.

If, then, we take upon A *i* any points 1, 2, 3, &c., and erect the perpendiculars to A B 11', — *m' n'*, — 22', — 33', which will meet the straight line D N in the points 1', — *n'*, — 2', — 3', by describing arcs of circles with the focus *m'* as a centre and radii equal to the perpendiculars 11', — *m' n'*, — 22', — 33', between A B and D N, the point in which each of the arcs cuts the perpendicular which has determined its radius will be a point in the ellipsis *n*, *n'*, *n''*, *n'''*.

If we now trace a curve passing through all the points thus obtained, we shall have the quarter of an ellipsis, and the other half of the arch may be formed in the same way.

3. Numerical value of the position of the foci.

We have as the value of the distance from the middle of the major axis to the foci :—

$\text{I } m' = \sqrt{\frac{Q^2}{4} - F}$, because of the rectangular triangle $m'\,i\,F$.

4. Numerical value of the position of the line D K.

We have as the value of the distance from the middle of the major axis to the point K where the line D N meets the major axis $i\,k = \frac{Q^2}{4\sqrt{\frac{Q^2}{4} - F^2}}$, because of the similar triangles D i K and D N i', whence D $i = \frac{Q}{2}$.

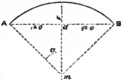
5. Values of the ordinates of the ellipsis.

The perpendiculars 1 n, — m' n', — 2 n'', — 3 n''', included between the major axis and the curve, are the ordinates of the ellipsis. The parts of the major axis measured from its extremity A : A1, — A m', — A 2, — A 3, are the abscissæ of the above-mentioned ordinates. Representing the abscissæ by x and the ordinates by y.

Section of Elliptical Arches.—We have $y = \frac{2\,F}{Q}\sqrt{\frac{Q^2}{4} - x^2}$; the area of an ellipsis being equal to π, multiplied by the product of the two half-axes, and representing the section of the arch by S, we have $S = \frac{\pi\,Q\,F}{4}$.

Determining the Joints of the Voussoirs.—When the thickness at the crown and at the springing has been decided upon, the thickness at the springing being greater than that at the crown, it will be necessary to trace the mean ellipsis, having just determined its foci: upon this ellipsis must be marked the divisions of the course of voussoirs. In each of these joints of division will be determined the bisecting line $y\,p$ of the angle formed by the two radii vectores drawn from each point of division, Fig. 1410.

1411.



Segmental Arches.—General values of the radius, rise and magnitude.

The chord of an arc or the span of a segmental arch being given, the radius of this arc is determined according to two different conditions, see Fig. 1411.

1. The rise required.

2. The magnitude in degrees and minutes which it is necessary to give to this arc.

The rise being = F, and the magnitude equal A, we shall have for R and F the following values :—

$$R = \frac{F^2 + \frac{Q^2}{4}}{2\,F}; \qquad [8]$$

$$F = R - \sqrt{R^2 - \frac{Q^2}{4}}; \qquad [9]$$

$$R = \frac{Q}{2\,\sin.\,a}; \qquad [10]$$

$$\sin.\,a = \frac{Q}{2\,R}; \qquad [11]$$

$$F = R - \cos.\,a \times R. \qquad [12]$$

Note on Trigonometry.—It will be necessary to give a few explanations of the chief terms used in trigonometry, to enable those of our readers who have not studied that science to employ the formulæ we have just adduced. The sine of an angle $a\,b\,c$, Fig. 1412, which we will call a, is the perpendicular $m\,n$ let fall upon $c\,b$ from the point m, where one of the sides meets an arc described from the summit b, as a centre with a radius of 1. The cosine of an angle is the portion of the side $c\,b$ included between the point n, the bottom of the perpendicular, and the summit b of the angle, the centre of the arc. The sine of an arc is the perpendicular $a\,d$ let fall from one of the extremities, a, of the arc upon the radius $c\,b$, passing through the other extremity, c, of the arc. The cosine of an arc is that portion of the radius included between the end of the sinus d and the centre b of the arc. The portion $c\,d$ is called the versed sine, and is equal to the radius $c\,b$ of the arc, minus the cosine $d\,b$. The tangent of an arc, $a\,c$, is the perpendicular $c\,t$ erected from the extremity of one of its extreme radii, $c\,b$, and included between its point of contact, c, and the point, t, where it is met by the other extreme radius, $a\,b$, produced. The cotangent is the tangent of the complement of the arc.

1412.

Chief Relations of the Trigonometrical Lines.—The sinus of an angle or of an arc is equal to the cosinus of its complement. The tangent of an angle or of an arc is equal to the cotangent of its complement, hence the formulæ:—Sin. a = cos. $(90° - a)$; . . . . tang. a = cot. $(90° - a)$.

There are two kinds of tables giving the values of the trigonometrical lines: those giving the logarithms of the values of these lines, and those giving their natural values. Of the former kind are the tables of Callet and De Lalande; of the latter are the tables of Richard, and those contained

in the works of Claudel and Chevallot. All tables are calculated for arcs having a radius of 1. They are usually arranged in the following manner: the number of degrees is marked at the top of the page from 0 to 45°, and at the bottom from 45° to 90°, because, as we have said, the sine, tangent, cotangent, and cosine of an arc are equal respectively to the cosine, cotangent, tangent, and sine of their complement. The number of minutes for angles or arcs from 0 to 45° are found on the left of the page, and for angles or arcs from 45° to 90° the numbers are on the right of the page. The values which are found in the horizontal line of each number of minutes, in tables of log. sines, cosines, &c., are the logarithms of the natural values of the sine, tangent, cotangent, and cosine of the angle or arc whose magnitude is expressed by the number of degrees at the top or bottom of the page, increased by the number of minutes found in the left column for the degrees which are marked at the top, and in the right column for degrees marked at the bottom. All these values, it must be remembered, are calculated for a radius of 1. In tables of log. sines, &c., the index is increased by 10.

From the fact of the values of the trigonometrical lines being given for a radius of 1, it follows from a comparison of the similar triangles $a\,d\,b$ and $m\,n\,b$, that the sine, tangent, cotangent, and cosine of arcs of different radii are to each other as their radii. Thus, when the value of a trigonometrical line has been found in the tables, we have to multiply this value by the radius of the arc in question in order to obtain its true value. The operations on the logarithms of the values of these lines are performed in the same way as on ordinary logarithms, and it will be necessary to remember that the characteristic of all these logarithms (Tables of Hutton) is increased by 10 units, and that the decimal part is always positive.

FORMULÆ GIVING THE DEPTH AT THE CROWN, AND THE PROPORTIONS OF THE RADIUS TO THE RISE, FOR ARCS OF GIVEN MAGNITUDES.

Elements of the Arcs.			Depth at the Crown = C.
Magnitude.	Radius = R.	Rise = F.	
°			
120	Q × 0·577	Q × 0·289	0·30 + 0·07 R; [13]
90	Q × 0·707	Q × 0·207	0·30 + 0·05 R; [14]
60	Q × 1·000	Q × 0·134	0·30 + 0·04 R; [15]
50	Q × 1·183	Q × 0·111	0·30 + 0·03 R; [16]
40	Q × 1·462	Q × 0·092	0·30 + 0·02 R; [17]

Segments having Magnitudes intermediate to those given in the preceding Table.—To determine the depth at the crown of segmental arches having magnitudes intermediate to those given in the Table, find the depth with the radius of the arc to be employed for the two magnitudes between which that of the given arc lies; a fourth proportional to the difference of the extreme magnitudes, to the difference of the depths at the crown corresponding to these magnitudes and to the difference between the given and one of the extreme magnitudes, will be the quantity which must be added to or subtracted from the depth at the crown corresponding to the extreme magnitude which has served to determine the fourth term of the proportion.

Example.—Let it be required to determine the depth at the crown of a segmental arch of 76° with a radius of 10 mètres.

We shall have for 90° and R = 10^m; C = 0·80
and for .. .. 60° and R = 10^m; C = 0·70

Differences .. .. 30° .. .. 0·10

Therefore $\dfrac{30°}{0·10} = \dfrac{90° - 76°}{x}$; whence $x = \dfrac{0·10 \times 14}{30} = 0·046$.

Hence for 76° and R = 10·00; C = 0·80 − 0·046 = 0·754, this arch would have Q = $12^m·312$, F = $2^m·12$.

The operation we have indicated will be indispensable only in the case of arcs of magnitudes lying between 120° and 90°, and 90° and 60°, because below 60° the formulæ giving the value of C for variations of 10° and the coefficients of R varying also by 10 thousandths, it will be sufficient to add to the coefficient of the magnitude next smaller, that of the one given, as many thousandths as there are degrees of difference between them.

By performing an analogous operation upon the rise, the calculation of magnitudes may be avoided. The differences obtained will not be exactly the same, but they will be near enough for practice, and the employment of trigonometry may thus be dispensed with.

Referring to the foregoing example, we have: R = 10^m; F = $2^m·12$; Q = $12^m·312$; whence $\dfrac{F}{Q} = 0·172$. The proportion of the rise to the span is included between the proportions 0·207 and 0·134 of the formulæ, Nos. 14 and 15. Proceeding in the same way as for magnitudes, we shall have

for $\dfrac{F}{Q} = 0·207$; R = 10^m; C = 0·80;

$\dfrac{F}{Q} = 0·134$; R = 10^m; C = 0·70;

Differences .. 0·073 .. .. 0·10

Establishing the proportion $\frac{0\cdot073}{0\cdot10} = \frac{0\cdot207 - 0\cdot172}{x}$, we shall have $x = \frac{0\cdot10 \times 0\cdot35}{0\cdot073} = 0\cdot048$.

Hence for $\frac{F}{Q} = 0\cdot172$ and $R = 10^m\cdot00$, $C = 0^m\cdot752$.

Thus this example proves that the radius and the rise of an arch being given, we may determine the depth at the crown easily by the aid of our formula without first considering magnitudes.

Gothic Arches.—The best form of Gothic arch is that consisting of two segments of 60°, in which R = Q. It is for this form only that we give a value for the depth at the crown, measured like all the preceding according to the vertical passing through the summit of the arch.

$$\text{In this case } F = Q \times 0\cdot866; \quad [18]$$
$$\text{and } C = 0\cdot30 + 0\cdot04\,R. \quad [19]$$

Lateral Thrust of Arches.—The following formula will furnish a means of verifying the depths at the crown, determined according to our formula, and the arrangement of the extrados, which we will discuss later. This formula denoting the horizontal thrust at the key is given regardless of an overweight or an accidental weight.

T = the horizontal thrust for a given length of the arch.
d = the weight per cubic mètre of the masonry.
C = the depth at the crown.
r = the radius of the intrados in semicircular arches; the radius of the curve at the summit in arches with any kind of intrados.

$$\text{We have} \quad T = \frac{d}{2}(2\,C\,r + C^2). \quad [20]$$

Arches of Cellars.—The depth at the crown of arches for cellars of dwelling-houses will be equal to the half of that of an arch of a bridge, of the same form and the same dimensions (span and rise) $\frac{C}{2}$.

Arches of Buildings.—The depth at the crown of arches of buildings, such as arches of churches, will be equal to $\frac{1}{3\cdot5}$ of that of an arch of a bridge, of the same form and the same dimensions (span and rise) $\frac{C}{3\cdot50}$.

MODIFICATION OF THE DEPTH AT THE CROWN ACCORDING TO THE NATURE OF THE MATERIALS EMPLOYED, AND THE GREATEST RADIUS OF CURVATURE.

The Radius of Curvature and the Employment of Material.—The general formulæ for the depth at the crown given in the preceding chapter were composed on the hypothesis that the employment of materials of various kinds, forming the intrados of arches, would be subject to the dimensions *minima* and *maxima* of the greatest radius of curvature of the arches, and which are shown in the following Table:—

Nature of the Materials employed.	Maximum Radius R.	Mean Depth.	Pressure on square 0·01 borne by the Masonry: At the Crown.	At the Base of the Piers.
	m.		k.	k.
Rough unhewn stone and concrete	2·00 to (3·00)	.. ..	1·00	5·00
Unhewn stone, regular in shape, such as calcareous limestones, laminated trachyte, or rough-hewn stone	4·00 to (5·00)	0·25 to 0·30	2·50	8·00
Stone slightly hewn and bevelled	8·00	0·33	4·00	12·00
Hewn or joggled stone and bricks	14·00	0·40	5·50	15·00
Cut or free stone	20·00	0·60	7·00	20·00

Above a radius of 20 the mean depth of the cut stone should be increased by 0·03 for each extra mètre of radius.

This Table has been constructed on the supposition that lime only moderately hydraulic will be used. For cases in which lime eminently hydraulic is employed, the values $3^m\cdot00$ and $5^m\cdot00$ are given.

The slightly hewn stone, or ashlar, as we understand it, should have its beds bevelled to the extent of 0·12, and the remainder of the bed not too much cut away; the joints should be perpendicular to the facing to the extent of 0·08. Hewn or joggled, stone should have 0·20 of its beds bevelled, the remainder of the bed not too much cut away, and 0·10 of the joints square with the facing. Cut or free stone should have 0·40 of its beds bevelled, and 0·25 of the joints square with the facing. These regulations for the cutting of the stone constitute the utmost allowance which may be made if the work is to be properly executed.

It is easily conceived that if, in the construction of an arch, whose greatest radius of curvature is 14 mètres, in which case we might employ hewn stone having a mean depth of $0^m\cdot40$, we use cut stone having a mean depth of 0·60, this latter having a larger bed, the pressure will be spread

over a larger surface of stone lying well together and of great resisting power. The masonry of rough stone for filling up the haunches might, in such a case, be reduced in proportion to this spread of the pressure over a wider and well-resisting surface.

Modification of Depth at the Crown.—Having regard to the preceding considerations, in order to take into account the various kinds of materials employed, with respect to—1, the radius of curvature to which it is to be applied; 2, the *maxima* to which each of them may be employed according to the resistance it offers, and in accordance with the spirit of the general formula which we have given; we have adopted the following rule for cases in which it is required to substitute for the materials considered in the general formula, as seen in the preceding Table, other materials capable of more or less resistance.

C = depth at the crown according to the general formula.
R = the radius of the intrados serving to determine the depth at the crown.

Let R' = the radius *maxima* for the materials to be substituted for those which might be employed, according to the preceding Table, and C' = the depth at the crown, modified by the materials substituted for those considered in the general formula of the Table.

We shall then have

$$C' = \frac{C}{\sqrt{\frac{R'}{R}}}. \qquad [21]$$

Example 1.—Let us consider a bridge with an elliptical arch in which $R = 8^{m} \cdot 00$, and in the construction of which slightly hewn stone might be employed. Supposing that it is wished to substitute for it cut stone, we shall have $R' = 20 \cdot 00$.

General value: $C = 0 \cdot 30 + 0 \cdot 05\, R = 0 \cdot 70$, whence $C' = \dfrac{0 \cdot 70}{\sqrt{\frac{20}{8}}} = 0 \cdot 51$.

The Table shows that for a radius of $20^{m} \cdot 00$ the cut stone should have a mean depth of $0 \cdot 60$; when the result obtained is below this limit the conditions are changed, and this shows that the radius *maxima* for the materials should be less than 20 mètres. We conclude from this that hewn stone should be substituted for cut stone, in order to keep within the limits assigned to each of these kinds of materials; and we shall have on this last hypothesis:—

$$C' = \frac{0 \cdot 70}{\sqrt{\frac{14^{m}}{8}}} = 0 \cdot 53.$$

Example 2.—Let us consider the viaduct of St. Germain, inserted under No. 8 in the Comparative Table.

We have $R = 5 \cdot 00$. Being semicircular, $C = 0 \cdot 30 + 0 \cdot 07\, R = 0 \cdot 65$.

In this case, according to the Table, slightly hewn stone should have been used; but unhewn millstone grit was employed, for which the Table gives $R' = 2 \cdot 00$;

$$\text{hence} \qquad C' = \frac{0 \cdot 65}{\sqrt{\frac{2}{5}}} = 1 \cdot 02.$$

The engineer, M. Flachat, gave $0^{m} \cdot 95$.

These two examples thus prove that the rule we have established takes into account all the conditions of resistance which result from the employment of different kinds of material.

The first example leads to the following conclusion:—Whenever the thickness at the crown, found for a kind of material that has been substituted for that which, in accordance with the Table, might have been employed, is less than the mean depth of the materials substituted, which depth is fixed in the Table, we ought to consider this substitution as impossible, and, further, to determine the *minimum* thickness at the crown with a kind of material of which the mean depth should not be greater than the thickness found for the crown. By proceeding in this manner, we shall keep within the bounds of safety, and be guided by a spirit of economy, which ought, except in circumstances of an extraordinary nature, to be considered in every undertaking. This *minimum* thickness being thus determined, it is obvious that it will be always allowable to employ cut for hewn stone, and hewn for slightly hewn stone.

Power of Resistance.—It will be advantageous to give the results of experiments made upon various kinds of stone and mortar, in order to obtain a general knowledge of their powers of resistance. It will be necessary, however, to remember that these experiments were made in the laboratory, where time and destructive atmospheric agents could have no effect. All bodies possess more or less elasticity; under the action of compression, or the reverse, their particles approach to or recede from each other; these actions have limits beyond which bodies lose the power of resuming their primitive forms when the pressure is taken off, and other limits beyond which, the force of cohesion being exceeded and overcome, a rupture of the particles takes place: the former is the limit of elasticity, the latter the limit of resistance to a crushing or a tractive power. As compression is, generally speaking, the sole influence to which masonry is subjected, we shall consider its employment only with regard to this. In practice, stone may be considered as incompressible; but when the pressure is exerted to a certain extent the hardest fly to pieces. The softer divide into two pyramids, whose bases are the upper and under surface of the stone, and whose summits are situated towards the centre; the side portions are driven outwards in the form of splinters. It has been remarked that stones begin to crack as soon as the pressure exceeds the half of that required to crush them; it is, therefore, at this moment that the cohesion of the particles is destroyed, and it is evident that this is the point which must not be exceeded in the

case of masonry having a weight to support. Even this limit should not be reached if the supports are isolated.

Experiments have shown that the weight which prismatic stones of the same nature will support increases nearly as their density. The weight which stones of the same form and nature will support is proportional to the areas of the transverse sections. The resisting powers of three prisms of the same weight and the same nature, having equal bases, are to each other as the numbers 703, 806, and 917, according as their bases are respectively rectangular, square, or circular; which shows that with an equal section a stone increases its power of resistance in proportion as it assumes the cylindrical form.

Representiug the resisting power of the cube by 1, that of the inscribed cylinder will be 0·08; that of the same cylinder, placed npon a sharp edge, 0·32; and that of the inscribed sphere 0·26.

It is easier to crush several stones placed one upon another than a solid block of the same form, the same dimensions, and the same nature. For three cubes placed one npon another, Rondelet discovered that the resistance was reduced about $\frac{1}{3}$, a result which the interposition of mortar diminishes, and which is explained by the want of perfect contact of the surfaces. According to Vicat, a cube of 0·03 loses $\frac{1}{8}$ of its strength when it is formed of eight small cnbes, and $\frac{1}{4}$ when it is composed of four equal prisms with fixed joints.

It follows from these facts that, having regard to the imperfections in the execution of work, in practice the permanent weight shonld not exceed $\frac{1}{15}$ of that necessary to fracture the stone, and that, further, in structures composed of ordinary stone or of small materials the $\frac{1}{12}$ or even the $\frac{1}{10}$ should not be exceeded. In the slightest structures the $\frac{1}{8}$ is not exceeded.

According to Vicat, a piece of masonry, composed of cut stone, will, after five months, support a weight of 200,000 kilogrammes per sq. mètre without any alteration of surface, and an average of 40,000 kilogrammes when constructed of nnhewn stone lying well together, with mortar moderately hydraulic. The quality of the mortar employed may increase or diminish the powers of resistance, as is shown in our Table of pressures which the masonry has to support. We give for arches a force of pressure which is abont $\frac{1}{4}$ or $\frac{1}{5}$ of that proposed by Vicat, and for perpendicular masonry it is nearly the same.

TABLE OF THE WEIGHT OF A CUBIC MÈTRE OF THE DIFFERENT MATERIALS EMPLOYED IN MASONRY WORKS, WITH THE PRESSURE PER SQUARE CENTIMÈTRE NECESSARY TO CRUSH THEM.

Nature of the Materials.	Weight of a Cubic Mètre.	Crushing Pressure to the Square Centimètre.
	kilos.	kilos.
Basalt and porphyry	2900	2000
Granite generally	2710	620
Sandstone, hard	2570	890
" soft	2490	4
Calcareous, chonchyllious and hard	2500	400
" compact (lithographic, lias)	2500	300
" oolite (globulous)	2100	110
" sandy	2000	100
Bricks, well burnt and hard	1600	140
" ordinary burnt (Belgian)	2160	100
Ordinary plaster, mixed stiff, 30 honrs after use	1570	50
" " less stiff	..	40
Concrete with hydraulic lime, 6 months after use	1830	40
Mortar, hydraulic lime, 15 days after use	..	4
" highly hydraulic lime, 15 days after use	..	8
" Vassy cement, half sand, 15 days after mixing ..	..	150
" highly hydraulic lime, 14 years after use	..	154
" ordinary hydraulic	..	80
" strong lime	..	20
See SPECIFIC GRAVITY.		

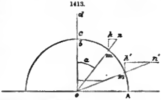
NOTE.—These resistances have been determined by experimenting upon cubes having a dimension of 0·03 to 0·05.

Plan of the Curves of the Extrados.—Tracing the Curves of the Extrados.—In arches constructed in one of the nsnal forms the pressure which acts through the curve of the arch, called the curve of pressure, is the resultant of all the forces acting upon this arch; and it is a principle that this pressure should increase from the crown to the springing. Hence it is necessary, to ensure the stability of the arch, that none of the points of this curve be without the section of the arch; for in such a case the pressure would not be directly supported. From this fact, and from the principle alluded to above, it follows that the thickness of an arch, measured normally at the intrados, which serves as a basis for the form of the curve of pressure, should increase from the crown to the springing.

We admit with M. Dnjardin, anthor of 'Routine des Voûtes,' that an extrados constructed so that *the vertical projection from the part of the radius of curvature of the curve of the intrados, produced to any point between the intrados and the extrados, be always equal to the depth at the crown*, complies sufficiently with the conditions of an increase of pressure, and gives the dimensions of the haunches of an arch in a way to render the disposal of the masonry similar to all points, Fig. 1413.

Let $o\,A = R$ and $b\,d = C$. Take any radius, $o\,m$, and at the point m erect a vertical $m\,h = b\,d = C$; through the point h draw the horizontal, meeting the radius $o\,m$ in the point n, to which the latter has been produced; the point n will be a point of the curve of the extrados, and $m\,n$ the thickness of the arch at the haunches. Proceed in a like manner for $m'\,n'$. By joining all the points thus found we shall have the curve of the extrados.

1413.



The numerical value of the thickness of the arch at the haunches will be as follows:—

Representing the angle $b\,o\,m$, formed by the radius drawn to a point m, at which point it is required to find the thickness of the arch by a; and the thickness of the arch by e; we have $b\,d = C$; and $e = \dfrac{C}{\cos. a}$.

This method of tracing the curve of the extrados is simple and practical. Figs. 1414 to 1416 are examples of arches of 10 mètres span.

Fig. 1414 is a semicircular arch; Fig. 1415 a segmental arch of 60°; and Fig. 1416 an elliptical arch. The slope of the abutments is in each case $\frac{1}{5}$. In the arch, Fig. 1416, the joint of rupture is determined by $\dfrac{V\,V'}{F} = \dfrac{F}{Q}$. In Fig. 1414 the joint of rupture is at an angle of 60° with the vertical.

Depths of the Crown.

Semicircular arches	$C = 0{\cdot}30 + 0{\cdot}07\,R.$
Elliptical	$C = 0{\cdot}30 + 0{\cdot}05\,R.$
Segmental of 60°	$C = 0{\cdot}30 + 0{\cdot}04\,R.$
„ of 50°	$C = 0{\cdot}30 + 0{\cdot}03\,R.$
„ of 40°	$C = 0{\cdot}30 + 0{\cdot}02\,R.$
Gothic	$C = 0{\cdot}30 + 0{\cdot}04\,R.$

Values of R.

Semicircular arches	$R = \dfrac{Q}{2}.$
Elliptical	$R = Q \times 1{\cdot}183 - 1{\cdot}366\,F.$
Segmental	$\begin{cases} R = \dfrac{F^2 + \frac{1}{4}Q^2}{2\,F}. \\ R = \dfrac{\frac{1}{2}Q}{\sin. a}. \end{cases}$
Gothic	$R = Q.$

Thickness of the Abutments at the Springings.

In all cases	$E = 0{\cdot}20 + 0{\cdot}30\,(R + 2\,C).$
Gothic	$E = 0{\cdot}20 + 0{\cdot}15\,(R + 2\,C).$

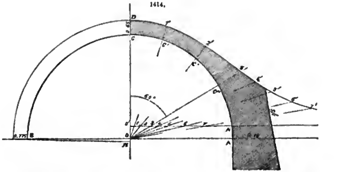
Thickness of the Piers at the Springings.

With 1 to 8^m span	$P = 2{\cdot}50 \times C.$
8^m and over	$P = 3 \times C.$

Strengthening of the Head-bands at the Springings.

$\frac{1}{4}\,Q \times 0{\cdot}025.$

1414.



Example 1.—Application of the method to a semicircular arch: $A\,B = Q$; $C\,D = C$, Fig. 1414. Upon $o\,c$ perpendicular to the line of the springing A B, erect from the centre o of the curve of the intrados, a line $o\,o' = C\,D = C$ the depth at the crown; and remark that $o'\,D = o\,C = R$; from

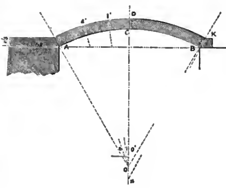
the point o' draw o' A' parallel to the line of the springing. Producing the radii $o c'$, $o c''$, $o c'''$, and so on; these radii will cut the line o' A' in the points 1', 2', 3', and so on; if we now continue these radii from the points 1, 2, 3, and so on, where each of them cuts the line A B to the points 1', 2', 3', 4', 5', 6', 7', making them equal to o' D and equal also to the radius of the curve of the intrados, we shall obtain a series of points D, 1', 2', 3', 4', 5', 6', 7', which will determine the curve of the extrados.

Remarking that each of the portions 0 1, 0 2, 0 3, and so on, is equal to c' 1', c'' 2'', c''' 3''', and that $o o'$ = C is the vertical projection from the portions of the radii 0 1, 0 2, 0 3, we see that this construction exactly fulfils the conditions already mentioned; that the vertical projection from a part of the radius of curvature of the curve of an arch produced to any point within the intrados and the extrados is always equal to the depth at the crown.

We would remark that the curve in question will never descend (in semicircular and elliptical bridges) to the level of the springing; for this curve which is determined by the sliding of the extremity o' of a line o' D along a line o' A', parallel to that of the springing and distant from this latter by a quantity equal to the depth at the crown, the direction of which in this sliding motion is compelled to pass constantly through the point o, the centre of the curve of the intrados, this curve is a conchoid of which o' A' is the asymptote. The point of the curve of the extrados nearest the plane of the springing will therefore be measured by infinity, and its distance from this plane would then be equal to the depth at the crown.

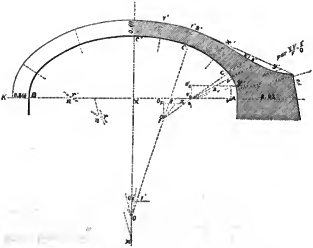
Example 2.—For the segment we have proceeded in the same way as for the semicircle; the determining of the curve of the extrados stopping with the last radius o A, Fig. 1415, it follows that the abutment rises above the plane of the springing by a quantity equal to the depth at the crown. In practice the extrados of the arch must be made to coincide with the top of the abutment according to the dotted line.

1415.



Example 3.—For the elliptical arch with five centres, Fig. 1416, we have proceeded for each arc of the ellipse in the same way as for

1416.



the half-circumference of the semicircular. Above each of the centres o, o, o, at a distance from these centres equal to the depth at the crown, draw a horizontal, then at each extreme radius of the arcs of the intrados find the points $1' - 2' - x' - y$ by the aid of the portions of the radii of curvature $11' = o c$, $22' = o_1 c'$, $x x = 22'$, $y y' = o'_2$ A.

For all elliptical arches, determine by the aid of a diagram the curve with 5 or 7 centres approaching as near as possible the given ellipsis of the intrados, and deduce from it the curve of the extrados as in the third example. In practice the extrados must be made to coincide with the abutment as shown by the dotted line.

Abutments and Piers.—Thickness of the Abutments at the Plane of the Springing.—Let E = the thickness of the abutments at the plane of the springing for arches of all forms, and H = the height of the abutments or piers. We have already R = the radius of the intrados serving to determine the depth at the crown, and C = the depth at the crown.

For any span and any form of arch we shall have

$$E = 0\cdot20 + 0\cdot30\,(R + 2\,C); \qquad [22]$$

except for the Gothic arch of two segments of 60, when

$$E = 0\cdot20 + 0\cdot30\left(\frac{R}{2} + Q\,2\,C\right).$$

The height of the abutments should not exceed

$$H = Q \times 1\cdot50. \qquad [23]$$

Except in cases of absolute necessity, the height should never exceed

$$H = Q \times 2. \qquad [24]$$

The first value of H will give to bridges of one arch the most solid appearance, a quality which public works ought to possess; it is also the limit of the conditions of great stability. The second value of H corresponds to the architectural proportions of a portico; it is also suited to large viaducts.

Facing of the Abutments on the Land Side.—The thickness of the abutments at the plane of the springing having been determined by formula [22], the exterior facing (the land sides) will be constructed with a talus of $\frac{1}{5}$ or 0·20 the mètre of height. The thickness of the abutments at the base will, therefore, be

$$= E + 0\cdot20\,H. \qquad [25]$$

This talus nearly corresponds with the retreats which many builders give to their works; this method, we think, ought to be abandoned on the ground of producing results opposed to those to obtain which it is adopted, namely, greater stability than with the talus. Each retreat is a reservoir of water furnishing a means of enabling it to penetrate the masonry.

In the case of the talus or slope we have taken the mean of the thicknesses at the springing and at the base. This mean may be taken in practice as the uniform thickness of the abutment, the value of which will be

$$E' = E + H \times 0\cdot10. \qquad [26]$$

In this case the exterior facing will be vertical. This arrangement will have the following inconvenience:—The pressure supported by the masonry on the level of the foundations will be much greater than that supported at the springing, a fact which might in certain soils be of grave consequences. Besides this, such an arrangement does not correspond in direction of resistance to the pressure of the arch.

The thickness of the abutments thus found needs no assistance of walls, which, if used, will be additional guarantees of stability. When massive walls are placed behind the abutments, if the sum of the mean thicknesses of these two walls be equal to half the width of the work between the headings, openings in the form of arches may be made in the abutments without endangering the solidity of the work. In this way a considerable saving may be effected.

It will not be prudent, however, to hollow the abutment between the walls throughout the whole of its height, for there should always be at the springing a mass of masonry of a width equal to that prescribed by the formula, to provide against the settling down of the masonry at the head and flanks of the arch in consequence of the slipping to which the latter is liable when there is not sufficient surface to resist the pressure.

Thickness of the Piers at the Springing.—Let P = the thickness of the piers at the springing, and F = the talus of the piers per mètre of height. For a span of 1·00 to 8 or 10·00 we shall have

$$P = C \times 2\cdot50, \qquad [27]$$

twice and a half the thickness at the crown.

For a span above $10^{m}\cdot00$ we have

$$P = C \times 3, \qquad [28]$$

three times the thickness at the crown.

Talus of the piers a mètre of height in all cases

$$\tfrac{1}{40} \text{ or } F = 0\cdot025. \qquad [29]$$

The body of the piers will thus increase to a mètre of height by $\frac{1}{20}$ or 0·05.

Besides this, it is well to give as much projection as possible to the socles in order to spread the pressure over a wider surface of natural ground. The nature of the soil, the importance of the work, the flow of the water, and the form of the foundation must guide the builder in the construction of the basis. His duty is to see that the works be firmly placed and protected from the undermining action of the water.

General Information.—According to statements made by Rondelet, in his 'Art de Bâtir,' we find:—

That thickness of the piers of a semicircular arch being = 1, the thickness of the piers for one and the same span will be, for—

Gothic arch of two segments of 60°	= 0·70	Elliptical depressed to $\frac{1}{3}$	= 1·35
Semicircular	= 1·00	" " to $\frac{1}{16}$	= 1·40
Elliptical depressed to $\frac{1}{4}$	= 1·18	Plat-band	= 1·40

That representing the thrust of a semicircular arch by 1, the relative thrust of other arches will be—

Gothic of two segments of 60° .. = 0·50	Elliptical depressed to $\frac{1}{5}$ .. .. = 1·93
Semicircular .. .. = 1·00	" " to $\frac{1}{10}$ .. .. = 1·91
Elliptical depressed to $\frac{1}{3}$ .. .. .. = 1·40	Plat-band .. .. = 1·95

Position of the Joints of Rupture.—It follows from the facts which we have gathered from various works, that the position of the joints of rupture in bridges of the semicircular and elliptical forms may be determined in a general manner by the intersection of a parallel at the level of the springing, with the curve of the intrados and the distance of which from the level of the springing is $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, or $\frac{1}{5}$ of the rise according as the rise itself is $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, or $\frac{1}{5}$ of the span. Calling V V′ this vertical distance, we have the proportion:—

$$\frac{\mathrm{V\,V'}}{\mathrm{F}} = \frac{\mathrm{F}}{\mathrm{Q}}, \text{ whence } \mathrm{V\,V'} = \frac{\mathrm{F}^2}{\mathrm{Q}}. \qquad [30]$$

This formula is strictly in accordance with the position of the joint of rupture in semicircular bridges, which is always considered as being on the radius inclined to 30° with the horizontal. In segmental bridges, so long as their magnitude is less than 120°, the joint of rupture is at the springing of the arch.

Proportions of the various Parts.—Head-bands of Arches.—These should have a greater thickness at the springing than at the crown. This arrangement, which is more rational than one of uniformity, gives the work a certain stamp of solidity; this kind of band is called strengthened.

In arches of moderate span, the thickness of the band at the crown is made equal to the body of the arch = C.

The thickness at the level of the springing being represented for all forms of arches by B, we shall have

$$\mathrm{B} = \mathrm{C} + \frac{\mathrm{Q}}{2} \times 0 \cdot 025;$$
$$\text{or } \mathrm{B} = \mathrm{C} + \frac{\mathrm{Q}}{80}. \qquad [31]$$

For a span not exceeding 4·00 the band may be parallel; for in such a case the increase would be hardly apparent, and it seems to us useless to introduce such a condition into small works.

In arches of a wide span, 20 or 30 mètres, the thickness of the head-band is often made less than that of the body of the arch. This reduction varies from 0·10 to 0·20, according to the hardness of the materials or the taste of the builder. While giving the work a bolder appearance, this reduction in no way compromises its solidity. It is besides quite in harmony with the principles which we have made known.

Tracing the Exterior Curve of the Head-band.—In semicircular arches the extrados will be determined by a segment, the centre of which will be below that of the intrados by $\frac{\mathrm{Q}}{2} \times 0 \cdot 025$, and the radius of this arc will then be equal to $\mathrm{R} + \mathrm{C} + \frac{\mathrm{Q}}{80}$.

In elliptical bridges, first determine the value of B, then divide the increase of the thickness of the band, or the difference between the thicknesses at the crown and at the springing, by the length of the half of the curve of the intrados (measured simply with the compasses); this will give the increase of the band for each mètre of length. Multiplying this quantity by the length, 1, of the half-arc of the summit, 2, of each of the other arcs of the ellipse, we shall have the thickness of the band at each change of curvature. The arc of the summit will be determined by three points, and will have its centre at *n*; the centre of the second arc will be found upon the last radius passing through *n*. It is besides determined in position by its two extremities, and its centre will then be at *n′*; in the same way we shall have the centre *n″*, Fig. 1416.

For elliptical arches we may also trace the ellipse of the extrados, the major and minor axes of which will be determined by:—The major axis = Q + 2 B, and half the minor axis = F + C.

In these kinds of arches the joints of the voussoirs should be traced according to the normals at the mean curve of the head-band, and not according to the normals at the intrados; by this means the pressure is distributed more equally on the planes of the joints. This arrangement corresponds in some degree to the inclining of the planes of the joints recommended in the learned work of Yvon-Villarceau on 'The Construction of the Arches of Bridges considered with regard to their Stability.'

For segmental bridges the extrados will be a segment having three points, the crown and the springings; its centre will be in *s*, Fig. 1415.

The Voussoirs.—The key voussoir ought always to be a header; and, as far as possible, the springers should be the same. Now the key is always like the first voussoir when the half of the total number of voussoirs of one head minus one is an even number. We are thus able to fix *a priori* the number of voussoirs to be put into an arch, and the builder will be guided by this in regulating the piers and abutments.

Plinths and Cordons.—Let the total height of the structure from the top of the foundations to the bottom of the plinths = H, the height of the plinth = *h*, and the ledge of the plinth = *s*, then in all cases

$$h = 0 \cdot 20 + 0 \cdot 02\,\mathrm{H}. \qquad [32]$$

For plinths without mouldings for small structures, $s = \frac{1}{2} h$;

" plinths with mouldings .. .. $s = 0 \cdot 70\, h$. [33]

When it is required to gain width and to place the parapet beyond the masonry, it will be necessary to put a console under the plinth, the height of which console will be $0 \cdot 70\,h$. We have P = the thickness of the piers.

Representing the height of the cordon also by h, we shall have

$$h = \frac{P}{7}. \qquad [34]$$

However, in cases in which the height of the cordon thus formed would exceed that of the plinth, it will be necessary to reduce it and to make it equal to this latter.

For details of mouldings, see Figs. 1417 to 1423.

Details.—Piers:—Thickness of the piers at the plane of springing:—

1st, up to 10 mètres span .. .. $P = 2 \cdot 50 \times C$.
2nd, under 10 mètres span .. .. $P = 3 \times C$.

Slope to a mètre in height, $0 \cdot 025$, or $\frac{1}{40}$.

Plinths and Cordons:—

Total height from the top of the foundations to the under-side of the plinth = H.
Total thickness of the plinth .. .. = h.

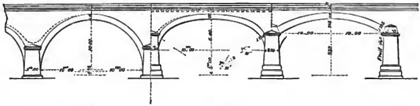
We shall have $h = 0 \cdot 20 + 0 \cdot 002 \times H$.

Ledge of the plinth { Small works .. .. .. $0 \cdot 50 \times h$. Large works .. .. .. $0 \cdot 70 \times h$.

Total height of the cordons $h' = \frac{1}{7}$ of the thickness of the pier. If this thickness exceeds that of the plinth, reduce $h' = h$.

The designs of cordon and plinth, Figs. 1417 to 1423, are specimens in which all the dimensions of ledges, plat-bands, and fillets are given, supposing the height h to be unity.

1417. 1418. 1419.



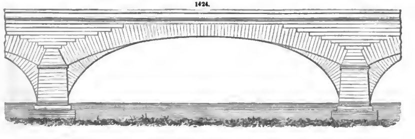
1420. 1421. 1422. 1423.

Buttresses.—The breadth of buttresses will be equal to the thickness of the plinth.

General Observation on the Construction of Arches.—We strongly recommend the placing of *bonders* here and there in arches of wide span; the bonders should be of cut stone of a mean depth twice that of the materials employed in the construction of the arches; iron cramps, set in cement, may be used to hold firmly together the stones composing the bonders. This latter arrangement has been tested by experience.

The arches of the celebrated bridge built by Perronet, over the Seine at Neuilly, one of which is shewn in Fig. 1424, are 128 ft. span, and the radius of the circle, of which the coincident portions

1424.



COMPARATIVE TABLE OF THE PRINCIPAL DIMENSIONS OF

No.	Name of the Work.	Present Dimensions. Number of Arches.	Span of the Arches.	Longest Radius.	Rise of the Arches.	Proportion of the Rise to the Span.	Magnitude of the Arc of the longest Radius.	Thickness: Of the Arches at the Crown.	Of the Piers at the Springing.	Of the Abutments at the Springing.
	1st. Semicircular Arches.									
1	Bridge at Romilly, over the Cheran	1	38·90	19·45	19·45	0·50	180°	1·62	..	..
2	Bridge at Avignon (Rhone)	21	31·36	15·68	..	"	"	0·74	6·96	26·43
3	Aqueduct of Spolette (Italy)	10	21·44	21·44	..	..	..	..	3·57	..
4	Bridge at Maligny	1	26·00	13·00	..	0·50	180°	0·92	..	3·65
5	Bridge at Furand, over the Furand	1	20·00	10·00	..	"	"	1·00	..	8·50
6	Viaduct at Stockport	22	19·80	9·90	..	"	"	0·84	3·04	..
7	Viaduct at La Manse, on the railway from Tours to Bordeaux	15	15·00	7·50	..	"	"	0·90	3·40	..
8	Viaduct at St. Germain (railway) ..	20	10·00	5·00	..	"	"	0·95	1·90	..
9	Viaduct at Beaugency (railway) ..	2500	8·40	4·20	..	"	"	0·80	1·60	2·60
10	Roadways over the railway (Tours to Bordeaux)	1	8·00	4·00	..	"	"	0·65 0·60	..	2·20
11	Roadways under the same	1	7·00	3·50	..	"	"	0·65 0·60	..	2·00
12	" "	1	5·00	2·50	..	"	"	0·55	..	1·50
13	Aqueducts, or small single arch bridges, under the same	1	2·00	1·00	..	"	"	0·29	..	..
14	" " (southern railway)	1	2·00	1·00	..	"	"	0·20	..	..
15	" "	1	1·00	0·50	..	"	"	0·40 0·30	..	0·55
	2nd. Elliptical Arches.									
16	Bridge at Gignac, over the Herault	1 2	48·72 25·34	35·89 12·67	13·30 12·67	0·275	..	1·95	7·80	11·05
17	Bridge at Nenilly, over the Seine ..	5	38·98	48·73	9·75	0·250	..	1·62	4·22	9·83
18	Bridge at Port de Piles (rail), over the Creuse	3	31·00	21·60	11·00	0·355	60°	1·30	5·50	7·30
19	Bridge at Auzon (railway), over the Vienne	5	20·00	14·50	6·67	0·333	"	1·10	2·60	10·80
20	Bridge at Bordeaux	17	26·50 to 20·80	..	8·81	0·332	..	1·20	4·20	..
21	Bridge at Chavannes	7	13·00	9·43	4·55	0·350	..	0·65	4·55	6·50
22	Bridge over the Brusche (railway in Alsace)	4	10·00	7·14	3·00	0·333	..	0·72	1·50	2·70
23	Bridge over the canal at Ellesmere (England)	1	4·90	3·66	1·83	0·373	..	0·31	..	0·92
24	Pont de l'Alma, over the Seine ..	1 2	43·00 38·40	53·75 50·56	8·60 7·70	0·20 0·20	.. ..	1·50 1·50	5·00 ..	.. 10·00
	3rd. Segmental Arches. 1st, 120° and over.									
25	Bridge over Doux, near Tournon ..	1	47·78	24·06	19·82	0·414	157° 34′	0·85	..	..
26	Bridge over the Conon (England) ..	5	one 19·82	11·10	6·10	0·307	127° 12′	0·92	2·44	..

BRIDGES, VIADUCTS, AND AQUEDUCTS CONSTRUCTED IN EUROPE.

Nature of the Materials of the Arch.	Date of Construction.	Name of Architect, and Observations.	Dimensions according to our Formulæ. Radius serving to determine the Depth at the Crown.	Depth at the Crown. According to the General Formula.	Depth at the Crown. Taking into account the Radius and the Materials.	Thickness at the Plane of the Springing, according to the general value of C. Of the Piers.	Thickness at the Plane of the Springing. Of the Abutments.	General Formulæ and Observations.
Freestone	1785	Garella	19·45	1·66	1·65	..	7·03	$C \begin{cases} 0{\cdot}30 + 0{\cdot}07\ R. \\ 0{\cdot}30 + 0{\cdot}08\ R. \end{cases}$ $E = 0{\cdot}20 + 0{\cdot}30\ (R + 2\ C)$ $P \begin{cases} 2{\cdot}50 \times C. \\ 3{\cdot}00 \times C. \end{cases}$
"	1177	Bénédie. The abutments include walls	15·68	1·40	1·24	4·20	5·74	
.. .. ..	741	The piers of this aqueduct are 89 mètres high, with a base of the same thickness as at the springing; the total height of the work = 130 mètres	..	..	..	..	..	The abutments should have an exterior talus of 0·20 per mètre.
Freestone	..	.. .. ..	13·00	1·21	0·98	3·63	4·83	
"	1834	Montluisant	10·00	1·00	0·70	3·00	3·80	The piers should have a talus of $\frac{1}{40}$.
Bricks, and a small quantity of freestone	..	Mean height of the piers = 20 mètres. No talus	9·90	0·99	0·82	2·97	3·76	
Slightly hewn stone	1847	Morandier	7·50	0·83	0·80	2·49	2·95	
Unhewn millstone grit, ordinary hydraulic lime	1845	E. Flachat	5·00	0·70	1·00	2·10	2·09	
Hewn stone	1845	Thoyot. Talus of the piers = 0·04	4·20	0·64	0·41	1·60	1·81	
Slightly hewn stone	..	.. .. ..	4·00	0·62	..	..	1·72	
" "	..	Thickness of the abutments uniform	3·50	0·50	..	..	1·58	
" "	..	.. .. ..	2·50	0·50	..	..	1·24	
Unhewn stone ..	..	.. .. ..	1·00	..	0·30	..	0·70	
Slightly hewn stone	..	Carvallo	1·00	..	0·30	..	0·70	
Unhewn stone ..	..	With light masses of embanking	0·50	0·34	..	..	0·55	
Freestone	1777 to 1793	Garipny	39·60	2·28	1·28	6·84	13·15	$C = 0{\cdot}30 + 0{\cdot}05\ R.$ $R = 1{\cdot}186 \times Q - 1{\cdot}366\ F.$
"	1774	Perronet	32·90	1·94	1·94	5·82	10·90	
"	1848	Beaudemoulin and Croizette-Desnoyers	21·60	1·38	1·38	4·14	7·50	
Hewn stone	1848	" "	14·55	1·03	1·02	3·00	5·18	
Bricks, with freestone bonders	1813 to 1822	Deschamps	19·30	1·26	1·20	3·78	6·75	
Freestone	1787	Gauthey	9·17	0·76	0·52	2·28	3·40	
Bricks	1845	Bazaine & Chaperon	7·76	0·68	0·50	1·70	2·94	
"	..	Telford	3·28	0·47	0·35	..	1·47	
Millstone grit, with Vassy cement	1855	De Lagalisserie and Darcel	39·50 33·00	2·27 1·95	2·00 1·65	6·00	11·10	Millstone grit with Vassy cement offers as much resistance as freestone. $C = 0{\cdot}30 + 0{\cdot}07\ R.$
Slightly hewn stone	1545	.. .. ..	24·06	1·98	..	..	8·60	$R = \frac{Q}{2 \sin. a}.$
Freestone	1809	Telford	11·10	1·08	0·72	2·16	4·18	$\sin. a = \frac{Q}{2\ R}.$

COMPARATIVE TABLE OF THE PRINCIPAL DIMENSIONS OF BRIDGES,

No.	Name of the Work.	Present Dimensions.						Thickness:		
		Number of Arches.	Span of the Arches.	Longest Radius.	Rise of the Arches.	Proportion of the Rise to the Span.	Magnitude of the Arc of the longest Radius.	Of the Arches at the Crown.	Of the Piers at the Springing.	Of the Abutments at the Springing.
	2nd, from 120° to 90°.									
27	Bridge at Vérone, near Vieux-Château	3	one 44·50	28·62	10·90	0·245	102° 01′	1·62	11·05	10·40
28	Bridge over the Taaf (England) ..	1	46·47	29·42	11·37	0·245	104° 20′	1·13	..	..
29	Specimen of passage over railway ..	1	15·20	10·75	3·15	0·207	90° 00′	0·90	..	4·65
	3rd, from 90° to 60°.									
30	Covered bridge at Flerence (Italy)	3	29·25	21·20	5·85	0·200	87° 17′	1·62	7·85	8·77
31	Bridge at Grosvenor, over the Dee (England)	1	61·00	44·23	12·20	0·200	87° 16′	1·22	..	14·64
32	Bridge at Munich (Bavaria)	3	31·20	26·00	5·20	0·167	73° 44′	1·30	2·92	9·75
33	Bridge at Glasgow	3	17·70	13·33	3·35	0·189	85° 10′	0·76	2·75	3·81
34	Specimen of passage over railway ..	1	12·00	10·00	2·00	0·167	73° 44′	0·75	..	1·90
35	Bridge at Brunoy	3	5·85	5·85	0·79	0·135	60° 00′	0·65	1·13	3·25
	4th, from 60° to 40°, and under.									
36	Bridge at Homps, over the Ande ..	3	21·40	21·40	2·87	0·135	60° 00′	1·30	3·57	8·77
37	Bridge at Val-Benoist Railway (Belgium)	5	20·00	20·00	2·68	0·135	60° 00′	1·00	2·50	..
38	Bridge at Etaples Railway (Amiens to Boulogne)	15	14·00	13·85	1·90	0·136	60° 44′	0·70	1·75	6·00
39	Pont d'Jéna, over the Seine (Paris)	5	28·00	31·35	3·30	0·105	53° 05′	1·44	3·00	9·75
40	Specimen of passage nnder railway	1	8·00	8·70	1·00	0·125	56° 8′ 40″	0·70	..	2·40
41	" " (Northern Railway)	1	7·40	8·50	0·90	0·122	51° 36′	0·65	..	3·86
42	Pont au Double, over the Seine (Paris)	1	31·05	41·67	3·00	0·096	43° 42′	1·60	..	..
43	Pont de la Concorde, Seine (Paris)	1	31·18	42·20	2·99	0·096	43° 20′	1·13	..	..
		2	28·26	38·86	2·66	0·094	42° 39′	1·05	2·92	..
		2	25·34	42·14	1·95	0·077	35° 00′	0·97	..	16·24
44	Bridge at Moret, over the Loing ..	3	25·30	46·77	1·85	0·073	31° 20′	1·30	2·43	..
45	Bridge at Nemours, over the Loing	3	16·24	30·21	0·97	0·060	15° 35′	0·97	1·95	4·87

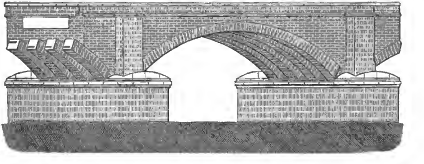
of the onter segmental arch are parts, is 160 ft. A comparison of this hridge with a hridge on the same plan, after the designs of Roy, will be found at No. 17 in the Table, page 698.

Along the line of the Highland Railway numerous hridges and viadncts have had to be erected. Fig. 1425 is of the viaduct which spans the river Conon, in Ross-shire. From circumstances it was necessary that this hridge should cross the river on a skew of 45° to the stream, and as there were rock foundations, there was no difficulty to contend with beyond that of 4 ft. or 5 ft. of water in the channel of the river to reach the rock. The peculiarity of the skew with the river at this place conld have been more easily provided for by the adoption of iron girders from pier to pier, but as it was found that iron girders would be fully as expensive and not so permanent as a stone bridge, and as there were admirable quarries in the neighbourhood, Joseph Mitchell, the engineer of the line, resolved to construct this bridge on a skew of 45° with the river, by a series of right-angled ribs or arches spanning from pier to pier. The bridge consists of five arches of 73 ft. span each, the arches being constructed of four ribs, each 3 ft. 9 in. wide; the arch stones are 4 ft. deep at the springing, and 3 ft. deep at the crown. The key-stones of the centre part of each arch were made to connect with each other, as were the stones in the haunchings of the arches, and some cramps of iron were inserted at the joints to connect the ribs. The work was

VIADUCTS, AND AQUEDUCTS CONSTRUCTED IN EUROPE—*continued.*

Nature of the Materials of the Arch.	Date of Construction.	Name of Architect, and Observations.	Dimensions according to our Formulæ. Radius serving to determine the Depth at the Crown.	Depth at the Crown. According to the General Formula.	Depth at the Crown. Taking into account the Radius and the Materials.	Thickness at the Plane of the Springing, according to the general value of C. Of the Piers.	Thickness at the Plane of the Springing, according to the general value of C. Of the Abutments.	General Formulæ and Observations.
Freestone	1354	.. .. ..	28·62	1·73	..	5·19	9·82	C = 0·30 + 0·05 R.
"	1756	Edward	29·42	1·77	..	..	10·06	
Slightly hewn stone	..	.. .. ..	10·75	0·88	0·85	..	3·94	
Freestone	1600	.. .. ..	21·20	1·34	1·24	4·02	7·06	60° C = 0·30 R + 0·04 R.
Granite	1832	Harrison	44·23	2·47	1·30	..	14·95	Granite having a resistance quadruple of the mean resistance of the other materials for which our formulæ are established, this difference of thickness at the crown need cause no surprise.
Freestone	1814	Wiebeking	26·00	1·45	1·45	4·35	8·87	
"	1835	Telford. The abutments are strengthened by curved butresses	13·33	0·95	0·70	2·85	4·77	
Slightly hewn stone	1850	Busch	10·00	0·74	0·74	..	3·64	
Freestone	1784	Perronet	5·85	0·54	0·40	1·35	2·28	50° C = 0·30 + 0·03 R. 40° C = 0·30 + 0·02 R.
"	1785	Ducros	21·40	1·25	1·16	3·75	7·36	
.. .. ..	1832	.. .. ..	20·00	1·10	..	3·30	6·86	
Bricks	1847	Bazaine	13·85	0·85	0·81	2·55	4·87	If the whole arch is of brick, we should only allow 0·70 at the crown.
Freestone	1809	Lamandé	31·35	1·31	1·31	4·02	10·40	
Slightly hewn stone	1850	Busch	8·70	0·61	0·60	..	3·18	
" "	1846	.. .. ..	8·50	0·57	0·55	..	3·09	
Unhewn millstone grit with Vassy cement	1847	De Lagalisserie ..	41·67	1·28	1·65	..	13·47	Comparing millstone grit with cement to freestone.
Freestone	1787 to 1792	Perronet. The thickness of the abutment is not excessive, it includes two counter-forts of 7·15 in. length	42·20 38·86 42·14	1·28 1·17 1·14	.. .. ..	3·51	13·53	
"	1771	Perronet	46·77	1·24	..	3·72	14·97	
"	1805	Designs by Perronet	30·21	0·90	..	2·70	9·26	

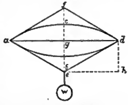
1425.



successfully accomplished, and constitutes a very perfect piece of bridge masonry. The total length of the bridge is 540 ft., and the height 45 ft. from the bed of the river. The north abutment is founded 304 ft. lower down the river than the south. The whole bridge was constructed for a single line of rails.

J. A. Roebling's System of Bridge-building: the Parabolic Truss.—Let $a\,c\,b$ and $a\,d\,b$, Fig. 1426, represent parabolic curves of the same deflection and span. The upper curve forms an upright arch, which presses against the points a and b. If these points are connected by the chord $a\,b$, and this chord balances the pressure at a and b, the chord and the arch will be in equilibrium and at rest.

1426.



The inverted parabolic arch $a\,d\,b$, freely suspended between a and b, will, on the other hand, produce an inside pressure upon these two points of support. If the two arches are equally and uniformly loaded, their strains at a and b will be the same, and in the directions of their respective tangents $a\,f$, $b\,f$, and $a\,e$, $e\,b$. We may therefore remove the chord $a\,b$, and in its place suspend the arch $a\,d\,b$; then the outward pressure, exerted by the upright arch upon a and b, will be met and balanced by the inward pressure at a and b, produced by the suspended arch $a\,d\,b$. The two arches are therefore in equilibrium, without any intermediate chord.

In a bowstring girder or arch nearly the same amount of material must be expended in the chord $a\,b$ which is required in the arch itself. But the chord adds nothing to the supporting power of the arch. On the other hand, by suspending the subverted arch $a\,d\,b$, we may dispense with the chord, and at the same time we have *doubled* the supporting power of the system. The great economy of the parabolic beam is therefore apparent at a glance. All that is required in practice is to provide sufficient panelling, and light bracing inside of the arches, in order to preserve their form and equilibrium under variable loads. It will be shown hereafter that a greater amount of material must be expended to obtain the same strength in other systems of girders and trusses.

To ascertain the forces of tension and compression at a and b, produced by the upright and suspended arch, draw the parallelogram $a\,f\,b\,e$, the sides forming tangents to the curves. The pressures caused by the upright arch will then be represented by $a\,f$ and $b\,f$, and the tension caused by the suspended arch is measured by $a\,e$ and $b\,e$. Suppose the weight W to represent the whole weight of the upright arch, then this weight will act through the linear braces $f\,a$ and $f\,b$ upon a and b, and its relative magnitude is represented by the diagonal f E, which is the resultant of the two forces $f\,a$ and $f\,b$. Let the pressure at a or b be donoted by P, then is $\mathrm{W} : \mathrm{P} = e\,f : a\,f$; and therefore, $\mathrm{P} = \mathrm{W}\,\dfrac{a\,f}{e\,f}$. Let x represent the deflection, or verse sine, $g\,c$ or $g\,d$, y — half the chord $a\,g$ or $g\,b$; and suppose the curves to be parabolas, then $g\,c$ will be equal to $c\,f$, or, $x = \frac{1}{2}\,g\,f = \frac{1}{2}\,g\,\mathrm{E}$; and $\overline{a\,f}^2 = \overline{a\,g}^2 + \overline{g\,f}^2 = y^2 + 4\,x^2$, or, $a\,f = \sqrt{y^2 + 4\,x^2}$. Substituting this value in the equation for P, and $4\,x$ for $e\,f$, we have $\mathrm{P} = \dfrac{\mathrm{W}}{4\,x}\sqrt{y^2 + 4\,x^2}$. The tension T, caused by the suspended cable at a and b, is equal to P, and found by the same formula.

As an example, let us suppose the span of the arch to be 500 ft., its verse sine 50 ft., and its total weight 500 tons; to find the pressure or tension at the points of support, we then have

$$\mathrm{P} = \frac{500}{4 \times 50}\sqrt{\overline{250}^2 + 4 \times \overline{50}^2}.$$

$$\mathrm{P} = 500 \times \frac{269 \cdot 25}{200} = 500 \times 1 \cdot 34.$$

$$\mathrm{P} = 670 \text{ tons.}$$

The figure 1·34 represents a variable coefficient, which is dependent upon x and y, but independent of the weight W. We may therefore, for convenience sake, compose a table of coefficients which will facilitate rapid calculations. The following Table gives the coefficients for versed sines of $\frac{1}{8}$ of the span to $\frac{1}{15}$:—

V. S.	$\frac{1}{8}$	$\frac{1}{9}$	$\frac{1}{10}$	$\frac{1}{11}$	$\frac{1}{12}$	$\frac{1}{13}$	$\frac{1}{14}$	$\frac{1}{15}$.
Coe.	1·118	1·23	1·346	1·463	1·58	1·70	1·82	1·94.

As an example, suppose a span of 1000 ft., verse sine $\frac{1}{8}$, or 125 ft., and load 1000 tons. The coefficient of pressure or tension in the Table is 1·118, therefore the pressure or tension is

$$1000 \times 1 \cdot 118 = 1118 \text{ tons.}$$

As another example, suppose the same span and load with a verse sine of $\frac{1}{15}$ of the span = 66·66 ft., then the coefficient in the Table is 1·94, and therefore the pressure or tension is

$$1000 \times 1 \cdot 94 = 1940 \text{ tons.}$$

It may be necessary to calculate the exact length of the arch, suspended or upright, measured by the curve. Let Z denote one-half the length of the curve, then is $\mathrm{Z} = \sqrt{y^2 + \frac{4}{3}\,x^2}$. This formula applies to a parabola, and is much more simple than the formula for a true catenary. It is sufficiently correct for practice, provided x is not greater than y.

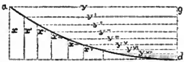
To determine the deflection x from the length of the curve and of the span, the following

equation will answer: $x = \sqrt{\frac{3}{4}(Z^2 - y^2)}$. These formulas are needed in order to calculate the rise or fall of an arch, due to its expansion or contraction from variations of temperature.

This diagram represents half a parabola, with its ordinates and abscissas. Now it is a property of the parabola that $x : x' = y^2 : y'^2$; from this we deduce $x' = \frac{x}{y^2} y'^2$; also, $x'' = \frac{x}{y^2} y''^2$; and so on. When, therefore, x and y are known, we can calculate the ordinates x', x'', x''', x^{iv}, for any abscissa. This will enable us to lay down the curve of the upright arch, or to calculate the length of suspenders for the suspended cable.

To ascertain the compression of the arch at its crown c, Fig. 1426, or the tension of the cable at its lowest point d, draw the lines $e\,h$ and $b\,h$ parallel to $g\,b$ and $g\,e$ in Fig. 1427; then the diagonal $b\,e$ represents the strain at b, while $e\,h$ represents the horizontal strain at d or c, and $b\,h$ represents the vertical pressure produced upon b or a, either by the arch or cable. $b\,h$ being equal to $c\,d$ or $2\,x$, of course the sum of the vertical pressures at a and b is equal to the whole weight of the arch or W.

1427.



In a similar manner can the compression or tension of the arch be ascertained at any other point of the curve by simply laying down a tangent and drawing out its parallelogram. The tension or compression is thus found to increase gradually from the centre to the points of support.

By laying down the curves accurately on a large scale, all the different strains may be measured by the scale sufficiently accurate for all practical purposes.

General Description.—The three openings of this bridge are spanned by two parallel continuous parabolic trusses, 1184 ft. in length, at a distance of 14 ft. apart in the clear; the floor beams for support of the track resting upon the lower chords. This superstructure is firmly fixed upon one of the two middle piers, while it rests upon roller-plates on all the other piers. This arrangement, therefore, admits of free contraction and expansion, caused by changes of temperature. It will be noticed that the towers which support the cables on the middle piers, form integral parts of the movable structure, and consequently will change their position in unison with the other parts of the work, when affected by contraction or expansion. The cables together with the arches form one united system, all moving together uniformly when thus influenced.

The railway track is supported at intervals of 5 ft. by rolled iron beams of 12 in. depth and 21 ft. 5 in. in length. The rails rest upon wooden stringers, 12 × 12, which are strengthened in depth by timber bridgings, 6 × 12, fitted in between the iron beams. A longitudinal iron beam of 9 in. depth underneath the bridging, suspended by bolts to the wooden stringer, adds further to the depth of bearing, which is wanted to distribute the concentrated weight of the locomotive drivers, and thus diminish their kneading action. Every second cross beam is suspended to the cables by means of suspenders, but each of the beams is also firmly riveted to the lower chords by sixteen rivets of $\frac{3}{4}$ in. diameter. This union forms the only connecting link between the arches and the cables.

There is one truss on each side of the track, and each is double throughout from end to end, leaving an open space 24 in. in width between the posts. In the centre of this space the cable is freely suspended in a vertical plane, parallel to the trusses; the suspenders run down in the same plane; so also do the wire-rope stays, which pass over the towers below the cables. Where the stays cross the suspenders, they are united with them by wire wrappings, for the purpose of preserving their straight lines, and to prevent oscillations.

The principal features, which give supporting strength as well as stiffness to the trusses, are the arches. The cables, which co-operate with the arches, are designed for strength alone, without adding much to stiffness. An additional source of strength as well as stiffness is obtained by the wire-rope stays, six on each tower; these are also very efficient in preserving the equilibrium between the spans under the action of variable loads, and also in relieving the arches at the haunches, where assistance is most needed.

At the extreme ends of the trusses four light double wire-rope stays are added to give additional strength and stiffness to those points.

At the first glance this plan may appear a complicated arrangement, defeating its own end by the want of internal harmony among its different parts. But no view could be more mistaken. In place of exhibiting a want of harmony, this system will be found in its practical working so co-operative and mutually supporting in its various parts, that nothing will be left to desire. No system is possible which, under the action of passing and variable loads, will be affected with perfect uniformity in all its parts, so that all the different members will be exposed to the same uniform proportional strain. Uniformity of strain in a plate-girder, in a lattice-girder, or in any other triangular or panelled truss, is out of the question. The arch alone, upright or suspended, comes nearer than any other system toward fulfilling this condition. When a load is placed upon any one point of the arch, the compression or tension thereby produced upon its section will be felt nearly alike throughout its whole extent, so long as its statical form is maintained. The capacity of the arch to maintain its form is strongest about the centre. Impressions upon the haunches are more apt to produce dislocations in other corresponding parts. To meet this weakness, stays are introduced next to the towers. So far as they extend, they are strong enough to support the maximum weight of that part of the structure as well as the load. Each stay in connection with the floor and tower forms a fixed triangle. This simple system of stays, as here designed, is the perfection of trussing. Nothing can be more perfect, or more simple, effective, and economical.

In the Niagara, Cincinnati, and Alleghany bridges, the conditions upon which the true action of stays depend are only partially fulfilled, because of the different material of the towers and the centrality of the floor. And yet with these drawbacks, the stays in these works answer such an admirable purpose, that they could not be supplanted by another arrangement. But in the plan before us all parts are composed of the same material, and are allowed to expand and to contract freely, and consequently their harmonious action cannot be disturbed on that score.

Suppose the section of the arch was doubled, and made strong enough to support a maximum load and the superstructure; and suppose, further, that its ends were connected by a chord strong enough to resist the thrust; all that would then be needed would, by common consent, be spandrils of sufficient stiffness to preserve its form under the action of variable loads. No engineer would doubt the stability of this simple arch. Now, in the plan before us, we employ the same arch, but of only half the section. This deficiency of strength is made up by the suspended arch; and in place of heavy spandrils we introduce a light panel-trussing throughout its whole extent, which will be found more effective in reality than any system of spandrils can possibly be made. This panel-trussing, judging from experience on the Niagara Bridge, will be found abundantly effective to preserve the form of the arch. If there were no adjoining spans, and if there were no necessity for towers for the support of the cables, nothing more would be needed. But the towers being there, the application of stays becomes at once one of the most economical as well as most efficient means to still further secure the stability of the whole system. Only fourteen panels are left without stays in the centre opening, reducing this distance to 280 ft. In this space the arch and the panel-work have to maintain their form alone, not counting upon the assistance of the cables. With reference to stiffness alone, the plan before us may also be considered in the light of a simple bowstring-girder, with this difference in favour of the Parabolic Truss, that the haunches of the arch are greatly assisted by the stays.

The harmony of action between the arches and cables, when under the influence of variable loads, now remains to be considered. Inside of the space of the central opening, between the two longest stays, a distance of 280 ft., a want of uniformity of action is utterly impossible, because the least impression upon the arch will be equally felt by the cable throughout its whole extent, and will be checked by the upward resistance of the superstructure. As the cable becomes depressed, every other point tends to rise, but is prevented by the weight and stiffness of the truss, the arch, and the panels. Considering now that the weight of the middle span is 640 tons, the local impression made by a 40-ton locomotive will be no more than is due to the natural elasticity of the material composing the truss. The cables being the most sensitive members of the system, their action will greatly tend to spread every local impression over a large extent, and thus neutralize its effects by engaging all parts of the system to resist.

So far as the stays extend, no local depression whatever can be produced, because every attachment of stay forms a fixed point, which, in connection with the arches, cables, and panel-braces, will be found sufficiently rigid to resist the severest local action beyond that due to the natural elasticity of the materials. Roebling is positive in this statement, because his observations on the suspension-bridges he built fully justify him in making it. If any one will take the trouble to scrutinize the action of the Niagara Bridge under the passage of a single heavy locomotive and tender with sufficient care and attention, and, by means of a level placed in one of the towers, will observe the progressive depressions of that structure, which take place from the tower toward the centre, he will discover scarcely any depression inside of the reach of the stays. Beyond the stays, toward the centre, the depression increases rapidly, and becomes greatest in the centre. Similar facts will be noticed on the Cincinnati Bridge, under the action of a number of heavily-laden teams, following each other in close succession.

The cables and stays are securely fixed upon the cast-iron saddles, which are mounted upon the tops of the wrought-iron towers by means of cushions, held down by screws. The height of the towers being 62 ft. above the base, and the supporting columns of an elastic material, they will yield a little, when one span is fully taxed with a maximum load, while the adjoining spans are empty. This yield will be imperceptible to the eye, but will no doubt be susceptible of measurement. And as this movement will not result from the free working of the different members of the system, but will be entirely due to the elastic yield of the materials, it may be repeated indefinitely without impairing the integrity and safety of the structure.

Since wire possesses a much greater degree of elasticity than bar-iron, one very great advantage of the cables and stays will be, that ordinarily, when not taxed by any load, the greater part of the weight of the structure will be borne by the wire. Under the action of light loads, the cables and stays will continue to bear the greater share; but when taxed with heavy trains, then the arches will also receive their full proportion. When the structure is relieved, the cables and stays will again contract and support the largest share. And so long as this process is kept within the limits of natural elasticity, allowing for an ample margin, the structure will remain perfectly safe and intact.

Each of the two cables is represented as composed of nineteen wire-ropes. Ropes will be found in practice to be the most economical means of forming the cables, also the easiest to put up, and the quickest. Cables made of wire laid parallel may also be constructed by those who have experience in this process, and know how to make a good cable; but the same amount of wire laid parallel into cables will give less strength than the same amount of wire laid into rope, provided the lay in the latter is long, and that its manufacture has been conducted with the necessary care and proper machinery. It is impossible to obtain perfectly uniform tension in a parallel cable, but it is possible to do so in a rope. The cost of the two, per pound, will be about the same, and of course the strongest should be preferred.

In place of making the cables of wire, they can also be made of iron or steel bands, provided the bands are rolled full length, so that they can be laid into the cable without splicing. The rolling of bands, say 4 in. wide and ½ in. thick, and 1000 ft. or more in length, is a process which

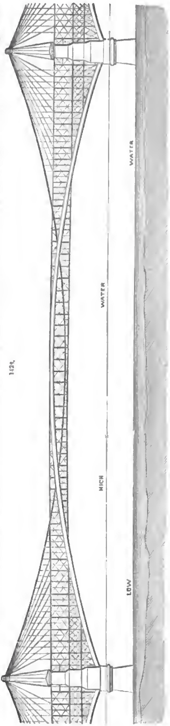
has never been attempted. But this process is perfectly practicable on a continuous mill constructed on the same principle as is Bedson's train.

The greatest depth of the superstructure in the central span is 44 ft., while its width is only 21 ft. 5 in. It is plain that this width is not enough to ensure sufficient lateral stability in heavy storms, or to prevent all horizontal oscillations under the passage of rapidly-moving trains. It must be observed that we are explaining the principle of Roebling on a bridge with a centre opening of 500 ft. and two side openings of 300 ft. each in the clear at low-water. Where one or two tracks are wanted for the accommodation of common travel, in connection with railroad traffic, either the floor for common travel may be placed overhead, above the railroad floor, or on the same level. If the latter arrangement is preferred, then an increased width becomes necessary, and this will still more add to horizontal stability. To ensure lateral strength, Figs. 1428, 1429, two wire-cables in horizontal parabolic curves have been laid down, anchored to one of the piers, suspended to the lower floor and fastened at intervals to the beams, which will ensure an ample degree of safety under all circumstances. These horizontal cables, forming one system with the flooring, will expand and contract alike with the superstructure; they can consequently be screwed up tight, to ensure their efficiency.

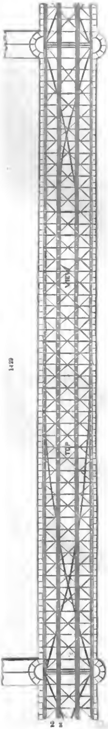
The top chords as well as the arches are sufficiently braced among themselves, horizontally, to impart to the superstructure a degree of internal rigidity; and the same system is also carried out vertically between opposite posts, every 20 ft., so far as the arches *rise above* the top chords.

Supporting Power of Stays.—The plan of stays is illustrated by Fig. 1430: $a\,b$ represents the tower; $a\,h$, the floor, at right angles to it; and $b\,c$, $b\,d$, $b\,f$, $b\,g$, and $b\,h$, are the six stays, their respective lengths marked in feet,

1429,

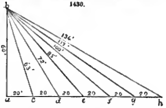


1429



fractions omitted. It is plain that the supporting power of the different stays is measured by the ratio of the height of tower to their different lengths. Thus, if we denote the supporting power of the stay bc by P, its ultimate strength by U, we have $P : U :: 60 : 63$; and $P = U\frac{60}{63}$.

1430.



In the same way for bd, $P : U :: 60 : 72$; and

$$P = U\frac{60}{72}.$$

The ultimate strength of each of these stays is assumed equal to 100 tons, and we therefore get their supporting power as follows:—

						Tons.
For bc	=	6000	÷	63	=	95·23
" bd	=	6000	÷	72	=	83·33
" be	=	6000	÷	85	=	70·58
" bf	=	6000	÷	100	=	60·00
" bg	=	6000	÷	117	=	51·25
" bh	=	6000	÷	134	=	44·77

Total supporting power of 6 stays, in tons	405·19
" " " 24 " "	1620·76
Allow $\frac{1}{5}$ of ultimate strength	324·15

Each stay produces a horizontal strain upon the lower chord, which is to its supporting power or vertical action, as is the base of the triangle to its height. Thus the horizontal action of the stay bc is represented by the base-line $ac = 20$, and its vertical action by $ab = 60$, and its direct action by $bc = 63$. If, therefore, the horizontal action is denoted by x, we find its value for

					Tons.
bc	x	=	$100 \times \frac{20}{63}$	=	31·74
bd	x	=	$100 \times \frac{40}{72}$	=	55·55
be	x	=	$100 \times \frac{60}{85}$	=	70·58
bf	x	=	$100 \times \frac{80}{100}$	=	80·00
bg	x	=	$100 \times \frac{100}{117}$	=	85·47
bh	x	=	$100 \times \frac{120}{134}$	=	89·55

Aggregate ultimate horizontal action of 6 stays, in tons	412·89
Allow $\frac{1}{5}$	82·58

	Tons.
The weight of the central span is, in tons	642
We will assume it at	650
The greatest possible transitory load which can be placed upon this span would be a train of locomotives, estimated at the rate of $1\frac{1}{2}$ ton a lineal foot, or for a length of 500 ft., at	750
Therefore, aggregate weight of superstructure and load ..	1400
Deduct the supporting power of 24 stays, allowing $\frac{1}{5}$ of their ultimate strength	324
Leaves for the support of the arches and the cables	1076

In order to avail ourselves fully of the economical principle of the Parabolic Truss, it is very evident that the tension produced by the cables should be exactly balanced by the compression of the arches, because the one supports the other. This exact balance of the two forces must exist at the anchor-plates, located at the ends of the superstructure, on the abutments, or on the piers, which serve as such.

These plates firmly hold the ends of the cables, and at the same time serve as supports for the ends of the arches. To further simplify this investigation at its present stage, we will assume that if the tension of the cables and the compression of the arches are equal to each other in the central span, then also the same balance will exist at the anchor-plates. This is not strictly the fact; but for the purpose of making the question plain, and to avoid intricate mathematical formulas, such as would not prove palatable to the practical engineer, and would, moreover, add nothing to the accuracy of this investigation, but, on the contrary, would tend to obscure the subject, at present, however, we assume it to be a fact.

The length of span from centre to centre of towers is 530 ft., and the deflection of the cables is 60 ft. The ratio of deflection, therefore, is 1 : 8·83. From the table of coefficients, we find the ratio of weight and tension for $\frac{1}{9} = 1·23$. It will be near enough to assume it here at 1·22.

The span of the lowest tier of arches is 516 ft., and its versed sine or rise 40 ft., and the ratio of deflection is 12·90 ft. The corresponding coefficient of compression in the table we find to be 1·70 ft.

Let us represent the weight to be borne by the cables by x, and the weight to be supported by the arches by y, then will be the tension of the cables $= 1·22\,x$, the compression of the arches

$1\cdot70\,y$. And since the condition is that the tension of the cables should equal the compression of the arches, therefore is $1\cdot22\,x = 1\cdot7\,y$. But the aggregate weight to be borne by the arches and cables was found to be 1076 tons. Therefore, $x + y = 1076$, or $y = 1076 - x$. Substitute this value in the previous equation, and we have $1\cdot22\,x = 1\cdot7\,(1076 - x)$, and $x = 626\cdot43$ tons; and also, $y = 1076 - 626\cdot43 = 449\cdot57$ tons.

From the foregoing we now find that the tension of the cable is $626\cdot43 \times 1\cdot22 = 764\cdot24$ tons.
Compression of the arches is .. .. $449\cdot57 \times 1\cdot70 = 764\cdot27$ tons, both about the same.

The question may be asked here, why the weight resting upon the arches and cables is not equally divided? If this was done, then it would be necessary to observe the same ratio of span and versed sine for the cables as well as for the arches. But this would reduce the deflection of cables, and thereby diminish their supporting power; or it would increase the rise of the arch and make the structure too top-heavy and too deep in the centre. On further investigation it will be discovered that the proportions here assumed are efficient and economical. The more weight thrown upon the cables, the cheaper the structure will be. But at the same time a certain amount must be reserved for the arches, else they will be too light, and the balance between the centre span and the side spans may be endangered under the action of heavy transitory loads. Each cable is composed of nineteen smaller cables or wire-ropes. The maximum tension of each rope is, therefore, $764 \div 38 = 20\cdot10$ tons.

Allowing six times the strength, we have the ultimate strength of each rope, $20\cdot10 \times 6 = 120\cdot60$ tons.

Each arch is composed of twelve channel-bars, 9 in. deep; we therefore find the maximum compression of each of the channel-bars, $764 \div 24 = 31\cdot83$ tons.

Allowing a maximum compressive force of 4 tons to 1 sq. in. of wrought iron, we get the section of each bar, $31\cdot83 \div 4 = 7\cdot96$ sq. in.

In the estimate of weight this section was assumed at $7\frac{1}{2}$ sq. in. average, at the same time allowing 25 sq. in. section for the top plates in the centre. The compression at the crown being less, the estimate is sufficiently correct for the present.

For much larger spans than 500 ft., it may be found more economical, and at the same time safer, to employ a mild steel for the arches, and also to manufacture the cables out of cast-steel wire. But it would be a mistake to do so in this plan, because the weight of the structure would thereby be too much reduced for safety, and its cost would be enlarged. To ensure a proper degree of stability between the spans under the action of heavy transitory loads, the weight of the structure should not be less than 1 ton to a foot lineal, for a single-track railway, on the supposition that the maximum transitory weights do not exceed $1\frac{1}{4}$ ton the foot. In this country, where 2 tons a foot are required by law, a greater weight of structure will be needed in proportion. But for the railway traffic of America, an allowance of 3000 lbs. maximum load for single track is amply sufficient.

The cables of the side spans form portions of the same curve as those of the middle span. The only difference is, that they are cut off 62 ft. beyond the centre. An exact half-span would measure 265 ft. from centre of tower to end of truss. But the actual length of the truss is 62 ft. more, which makes 327 ft., the object being to make the side spans about 300 ft. in the clear at low-water mark. Whether the cable is anchored at that point or is continued, its tension will not vary, provided its weight or load per unit of length remains the same. In proportioning the arches of the side spans, two conditions have to be fulfilled. Their horizontal thrust at the foot of the towers must balance the horizontal pressure caused by the arches of the central span. Secondly, their horizontal pressure against the anchor-plates must balance the horizontal tension of the cables at those points. These two conditions will determine the proportions of the arches as well as the length of the spans. If, on the other hand, the length of span is fixed, we can also proportion the arches and cables so as to fulfil the above conditions. An easy and practical method for a preliminary investigation, is to lay down the curve of the table, then construct a full arch, similar to the central arch, on thick drawing-paper, cut out its curved outline and lay it down upon the plan; then try its various positions, to find out approximately what length of span and what proportions will about suit. This examination made, we can then calculate the proportions of the arch, its supporting power, and its pressure at the foot and at the anchor-plate. This process, repeated a few times, will bring us near enough to the exact quantities which are required. A practical method like this will be found much more satisfactory, and at the same time easier and more certain than the use of complicated equations.

By lowering the anchor-plate, we shorten the cable until we have reached its centre, which forms an exact half-span. By raising the anchor-plate, we lengthen out the span, and the greatest length will be obtained when the plate is at the level of the upper chord. In that case the arch would have to rise *above* the upper chord. On the other hand, we can also reduce this span to less than a true half-span by moving the anchor-plate back until we meet the upper chord. This point of intersection will then have a strong tendency to rise, which must be met by anchoring to the masonry in such a manner that contraction and expansion from changes of temperature will not be interfered with.

Strains in Arches and Cables.—The trusses of the side spans are 327 ft. long, measured from the centre of tower. The arches of the side span form part of a curve whose chord is 352 ft. in length with a versed sine of 18·8 ft. The ratio of deflection to span is therefore as 1 : 18·72, and the coefficient of compression 2·4.

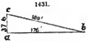
The greatest weight upon the arches of the central span is 450 tons.
Or per foot lineal, $450 \div 500 =$ .. .. 0·9 „

The weight upon the side arches will be nearly the same per lineal foot, and we will compute

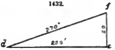
their compression by supposing their whole length weighted down at the same rate. This gives a total weight of $352 \times 0 \cdot 9 = 316 \cdot 8$ tons. Hence their compression at the foot of tower, $316 \cdot 8 \times 2 \cdot 4 = 760 \cdot 32$ tons.

To illustrate:

1431.



1432.



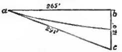
Let $d e$, Fig. 1432, represent half the chord of the central arch, 258 ft. long, $e f$ twice the height of its rise, equal to 80 ft., then the hypothenuse $d f$ will form a tangent to the arch, and will measure 270, omitting fractions. Now, the compression of this arch is represented by $d f$, its horizontal thrust by $d e$, and its vertical pressure by $f e$. Consequently, we find the horizontal thrust of the central arches (since the compression is $449 \cdot 57 \times 1 \cdot 70$)

$$764 : x :: 270 : 258\, x = \frac{764 \times 258}{270}, \text{ or } x = 730 \text{ tons.}$$

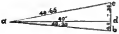
Also let $a b$, Fig. 1431, represent half the chord of the side arch, equal to 176 ft., and $a c$ its double rise, equal to 37·6, then $b c$ represents the tangent, and will measure 180 ft. The horizontal thrust of the arch is then found, $760 : x = 180 : 176\, x = \frac{760 \times 176}{180} = 743$ tons. There is a difference of 13 tons on the part of the side arch, which is readily met by the strength of the lower chord and the stability of the foot of the tower.

Again, let Fig. 1433 represent a rectangular triangle, where $a b$ is one-half of the main span or 265 ft., $b c$ twice the versed sine of the cables or 120 ft., then $a c$ is the tangent, equal to 291, and represents the tension of the cable, while $a b$ is its horizontal force, and $b c$ its vertical pressure. We therefore find the horizontal force or x; $291 : 265 :: 764 : x = \frac{265 \times 764}{291} = 696$ tons.

1433.



1434.



In Fig. 1434, let a be the centre of the anchor-plate, $a d$ a horizontal line 40 ft. long, $b c$ vertical to it; then make $d c = 7 \cdot 25$, and $d b = 4 \cdot 0$, $a c$ will be $= 40 \cdot 65$, and $a b = 40 \cdot 20$; $a c$ represents the tangent of the arch, and $a b$ the tangent of the cable. In order to find the horizontal force of the cable and arch at a, we must first ascertain their relative tension and compression at this point.

	Tons.
The tension of the cable at the top of the tower is	764
And in the centre of the curve	696
Difference	68
The decrease of tension being nearly uniform, we find the tension at the anchor-plate about	712
The compression of the arch at the tower is	760
And at the centre	743
Difference	17
The compression at the anchor-plate we find about	747

We can now ascertain the horizontal force of the cable at the point a:

$$712 : x = 40 \cdot 20 : 40 \cdot 00\, x = \frac{712 \times 40}{40 \cdot 2} = 708 \text{ tons.}$$

In the same way the horizontal thrust of the arches is found:

$$747 : x = 40 \cdot 65 : 40\, x = \frac{747 \times 40}{40 \cdot 65} = 753 \text{ tons.}$$

The horizontal pressure of the arches is therefore 27 tons greater than the horizontal force of the cables. This excess is easily met by the resistance of the framing, composed of the upper and lower chords, and by the action of the abutment-stays. A few light tie-rods, extending from the anchor-plates to the lower chords, will also balance this excess. But if there was a necessity to establish an exact balance between the horizontal action of the arches and cables, without changing the length of span, all that would be required is to shorten the full chord of the arch, and to increase its versed sine a few feet, which change would pass them through the upper chord. This change is not desirable, but may be met by increasing the height of the trusses to the same extent. Roebling, however, prefers to leave the proportions as they are, because the ends of the side spans will be found in practice to need more stiffness than other parts of the work, and this will be obtained by an increase of stiffness in the arch.

To add still more to the stiffness of the ends, four light wire-rope stays or ties have been introduced, of sufficient strength to prevent oscillations. To meet the horizontal action of these stays an excess of strength will be found in the upper and lower chords. Another object of these stays is to resist the downward pressure of the three wire-rope stays below the floor. The object of these stays is threefold. First, they will assist in preventing oscillations from passing loads; secondly, they will resist the uplifting tendency of heavy storms and hurricanes; and, thirdly, they will

greatly assist the free and easy expansion of the structure caused by a great increase of temperature. Such assistance is desirable in case of a single-track bridge, when care must be had to provide enough safeguards to maintain lateral stiffness and to prevent the structure from getting out of line. The great tendency of the cables to assume a vertical plane will of course contribute very much to the horizontal stability of the arches; but it is still advisable to avail ourselves of such a cheap and effective auxiliary as will be provided by these under-floor stays. Their tension should be adjusted so that a maximum contraction in the winter caused by their own shrinkage and the shortening of the superstructure will not overtax their strength. But it will be observed that the tighter they are the more power they will possess to pull the structure back, when an increase of temperature occurs. On that side of the main span, where its whole length, together with one side span, expands and contracts in one, still longer stays may be applied, if it should be found desirable; and also heavy weights suspended to it to give them more deflection without an increase of tension, and thus to render them more efficient and safe in the performance of their task.

The ends of the trusses are further secured vertically, as well as laterally, by two wire-ropes, one on each side of the structure, anchored to the pier by joints, which will admit freely of the movement of the upper ends, where they are fastened to the top chords, in accordance with the contraction and expansion of the structure.

Statical Condition of the Structure under the Action of variable Loads.—Suppose a maximum transitory weight of 750 tons evenly distributed over the whole length of the central span, and no loads upon the side spans, what will be the statical condition?

The following Table exhibits the relative portions of weight borne by the stays, the cables, and the arches of the central span when taxed with a maximum load, including superstructure.

	Weight of Superstructure.	Transitory Load.	Total Weight.
	tons.	tons.	tons.
Borne by stays	150	174	324
" cables	290	336	626
" arches	210	240	450
Total	650	750	1400

We will first consider the action of the stays. This action is twofold: first they exert a force upon the top of the tower, which may be resolved in a horizontal and vertical direction, and will be fully considered hereafter. Secondly, their force produces a horizontal tension as well as compression upon the lower chords. Now, as there is a system of stays on each side of the tower, if their horizontal action is the same, the compression of the chords on the one side will be met by the compression on the other side, and there will be equilibrium. But if the side span is relieved of its transient load, while the main span remains loaded, then the equilibrium between the opposite stays will be disturbed. The tension of the stays on the side span being relieved, the top of the tower will slightly yield toward the main span, as far as will be permitted by its inherent elasticity and stiffness. This will partially restore the lost tension of the stays, and the horizontal compression of the chords will remain nearly the same. No other change can result, because the stability of the towers will be maintained by the leverage of the side span, as will appear hereafter.

Next, let us consider the condition of the central arches, under a pressure of 240 tons produced by the transitory load, without any corresponding weight upon the arches of the side spans. The compression at the foot of the arches, caused by the above weight, is $240 \times 1 \cdot 7 = 408$ tons, and the horizontal thrust, Fig. 1432, $408 \times \frac{258}{270} = 390$ tons.

The ends of the arches being connected by the lower chords and framing of the floor, these parts will be exposed to this thrust most directly. Allowing 5 tons maximum tension a sq. in., a section of $\frac{390}{5} = 78$ sq. in. will be required. Now the lower chords are composed of eight channel-bars of $7\frac{1}{2}$ sq. in. section each, making 60 sq. in. Add the sections of the 9″ girders, underneath the tracks, which are brought into full action by the braces at the towers, 18 sq. in. Total, 78 sq. in.

The excess of pressure of the central arches is therefore fully met. But the three spans form one continuous truss, and consequently a great resistance will also be offered by the upper chords and by the inherent stiffness of the whole structure. It is therefore plain, that so far as the arches are concerned, their stability and safety under the action of the heaviest transitory loads are sufficiently secured.

It remains now to examine the conditions brought about by the united action of the cables and stays when taxed by a maximum load in the main span, without corresponding loads in the side spans.

	Tons.
The weight upon the cables caused by this load is found in the above Table ..	336
And the tension at the top of towers, $336 \times 1 \cdot 22$	410
The horizontal force acting at the saddle is found to be, Fig. 1433, $410 \times \frac{265}{291} =$	373
Add to this the horizontal force produced by 12 stays	165
Total	538

Now this combined force acts upon the top of the towers, its height serving as a lever, with a tendency to lift the adjoining side span. The moment of this force, therefore, is $538 \times 62 = 33356$.

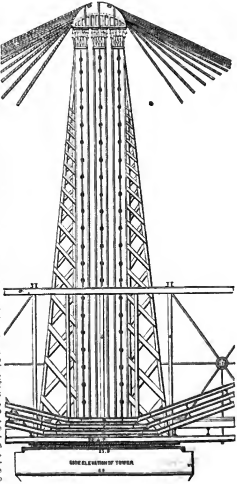
The weight of superstructure of the middle span was assumed at 650 tons, or per foot lineal $\frac{650}{500} = 1 \cdot 3$ ton. The weight of the side span per foot lineal is about $1 \cdot 2$ ton. The length of the side span is 327 feet. Consequently its total weight, $327 \times 1 \cdot 2 = 392 \cdot 4$ tons.

This weight may now be supposed as acting at the centre of the span, and the leverage of its action in maintaining the stability of the whole, is equal to half the length of the span; consequently the moment of force is $392 \cdot 4 \times 163 \cdot 5 = 64157$.

But the end of the side span is held down and kept from rising by the stays underneath the floor and by the two powerful wire-rope braces which secure their lateral position. These combined resistances may be estimated at least at 100 tons, and this force acts with a leverage equal to the whole length of the side span; consequently its moment is $327 \times 100 = 32700$.

1435.

1436.



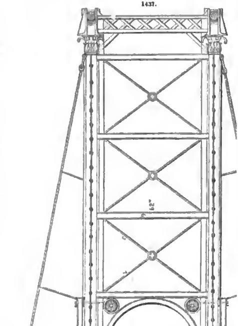
Total moment, 93,857, or nearly three times as much as is needed to maintain an equilibrium.

The above investigations authorize the conclusion that this Parabolic Truss is not only amply strong in all its different parts when uniformly loaded, but that its safety and stability are also amply provided for under the variable action of maximum loads. Indeed, when comparing the rates of allowances made in this plan, with those usually observed with iron railway-bridges in this country, where cast iron is so abundantly made use of, it would almost appear there is an unnecessary strength provided for.

Roller-plates.—The whole length of parabolic superstructure is 1184 ft., and forms one single continuous truss, whose integrity and continuity must not be interfered with in any way whatever. Hence the great importance of providing for efficient means to facilitate the free contraction and expansion of the work in consequence of changes of temperature. The superstructure is permanently fastened and anchored upon one of the middle piers, and from this fixed point the side span adjoining is allowed to expand and contract. A roller-frame is therefore placed upon the abutment, or upon the pier, which serves as such. On the opposite side, the middle span together with the side span contracts and expands as one, and consequently roller-frames are placed upon the second middle pier, as well as upon the abutment.

No strife or interference between the different parts of the structure can take place while this process of contraction and expansion is going on, because all parts are made of the same kind of material—wrought iron—and therefore the arches, cables, chords, and towers will go and come in the same relative ratio. When the temperature increases, the chords, arches, and cables will increase their length, and the whole structure will be lengthened out. The panel or truss posts will increase their length: in the same ratio the arches will rise and the

1437.



FRONT ELEVATION OF TOWER

cables will sink, preserving a uniform tension among the suspenders and panel-rods. At the same time the towers will raise their heads and compensate for the increased length of cables and stays. The whole truss may be considered as fastened to one metallic sheet in a vertical position, expanding or contracting in all directions.

A bar of wrought iron 150,000 ft. in length will expand or contract 1 ft. for every degree of change. Now assuming the extremes of temperature at 150°, the extreme limit of contraction and expansion of one middle and side span, which measures 857 ft. in length, will be 0·857 ft. The roller-plates on that abutment must therefore allow of this much play. Whether the temperature of the iron rises to 120° in a July sun, or falls to 30° below zero in the dead of winter, we are sure that all parts of the structure will freely accommodate themselves to these changes, and will never fail on that account to support their allotted parts.

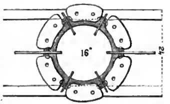
An inspection of the cross and longitudinal section of roller-plates, Fig. 1435, will make their simple construction perfectly plain. Both the upper and lower plates are of cast iron; the rollers between are of wrought iron. The inner faces of the plates must be planed off true, so that the bearing of the rollers, which are all turned off to the same diameter, will be even and uniform. It is customary to connect the rollers by a frame; but this is an unnecessary expense and no improvement. The edges of the rollers are slightly rounded off, say ½ in., and the plates confine the rollers between flanges 1 in. deep. These flanges are sloped ½ in., which prevents friction between them and the rollers. At the same time the slope is too steep to admit of the mounting upon it of the edges of the rollers. To ensure parallelism between the rollers, they are placed together where the pressure is very great, and where the pressure is light, as in the case before us, they are spaced by inserting between them strips of seasoned pine-wood well soaked in linseed oil. With the weight of the structure upon the plates the rollers will keep their relative positions. It is easier and cheaper to ensure parallelism on this plan than by the employment of roller-frames. Steel rollers are sometimes used in place of iron rollers. But this is objectionable in connection with cast-iron plates. The rollers on the towers of the Niagara Bridge are made of cannon-metal, and are 5 in. in diameter. When steel is used for rollers, both plates should be faced with steel; if not, then the hard rollers will make an impression on the softer cast iron.

The rollers exhibited, Fig. 1435, are 4' 4" long and 3" in diameter. The plates are 3" thick. The lower plate is well settled on a heavy bed of rich cement-mortar. The wooden strips between the rollers are not represented on the plates which support the tower, Figs. 1436, 1437.

Towers.—The towers are 62 ft. high above the roller-plates. Each tower, Figs. 1436, 1437, is composed of two shafts, which form parts of the trusses, and are firmly connected with the chords and arches. Each of the shafts is composed of three columns, and each column again may be constructed either of four, six, or eight sections. Fig. 1438 exhibits a section of a column composed of six segments. In Figs. 1436, 1437, the columns are drawn with four segments only. The interior circle of the column is assumed at 16 in. The shafts being 59' 2" high from the roller-plate to the saddle, the sections may be rolled about 20 or 30 ft. long, so as to break joints. Every joint must be covered by a splicing-plate inside. The intermediate plates which connect the

segments, also breaking joints with them, will likewise add to the firmness of the columns. Both ends of the columns are to be planed off true, and so must be the end of every intermediate piece, so that every joint will make a tight fit. The respective columns of the opposite shafts are connected horizontally by a system of channel-bars and diagonals, which will fully ensure their lateral security. This is further increased by two lattice-beams, which connect the cast-iron saddles, as is plainly exhibited in Fig. 1437. The top roller-plate being planed off on both sides, the lower ends of the columns will have a fair level seat upon them. The shafts are thus enclosed between the foot of the arches and the lower chords, and firmly connected with them laterally by flat bars, angle-irons, and stay-bolts. When the flanges of the inner channel-bars and those of the columns meet and interfere with each other, they are cut away for a few inches. The truss-posts at the towers are also firmly connected with the shafts, and so are the upper chords, and these connections will add much to the strength of the structure. In the direction of the trusses each tower is further secured by four lattice-braces which run between the chords and arches. The stability of the towers in this direction is also increased by the stays, and in a lateral direction two powerful wire-rope guys add to their security. These guys serve as anchors, and being hinged at the lower ends, will not interfere with the free contraction and expansion of the structure. To guard against lateral vibration of the lattice-braces, their outer chords are strengthened by plates 12 in. wide and ½ in. thick, riveted to a heavy T-bar which connects with the lattice-bars, Figs. 1560 to 1563.

1438.



It will be noticed that the towers, forming one connected whole with the trusses and arches, will move freely on the roller-plates along with the rest when affected by contraction and expansion on that pier which is provided with rollers. On the other piers the towers are stationary.

The greatest vertical pressure upon one tower (two shafts) is equal to 950 tons. Allowing 4 tons maximum compression for 1 sq. in. section of iron, we should require $\frac{950}{4} = 237\frac{1}{2}$ sq. in., or $118\frac{3}{4}$ sq. in. in each shaft. In place of this, we have allowed a section of 150 sq. in., which reduces the pressure upon each superficial inch to 3·16 tons at the top of the tower. As we descend, the strength increases considerably by aid of the lattice, and when the upper chords are reached the strength is nearly doubled. We are therefore sure that ample allowance is made for the supporting power of the towers.

Saddles.—The saddles on top of the towers are of cast iron, 8 ft. long by 3 ft. 6 in. wide at the bottom plate. The construction is given in Figs. 1436, 1437. The lower face is planed off, so that when the top of the columns is brought to a level, the two surfaces will have a fair and equal bearing. In order now to secure the saddle horizontally, six small segmental plates are fitted around each column, and secured to the bottom of the saddle by set screws. To do this, an exact template should be formed of the top of the shaft, before the saddle is hoisted; then the holes may be marked off for the set screws, and sunk into the saddle: the small plates can then be screwed on to its lower side before the saddle is finally put in place.

The inside section of the saddle is so shaped that the wire-ropes for supporting the cables and stays will occupy their relative positions. Four ropes are placed in the bottom row; they, together with the two outside ropes of the next tier, compose the six stays. The next three middle ropes, the second tiers, form the lowest layer of the cable.

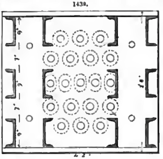
Two forged pieces of wrought iron 4" × 6", with triangular pieces underneath, are let into the four notches of the sides of the saddle and screwed down for the purpose of securing the cables and to prevent sliding. This being done, the cables and tower now form one. When there is a greater strain on one side than on the other, the elasticity of the tower will admit of sufficient yield to equalize the difference.

Anchor-plates.—The end of each cable is secured to a cast-iron plate, which at the same time serves for the arch to butt against, and thus the two are made to balance each other. Figs. 1439 to 1441 exhibit views of both faces of the plate, and also a section in which the fastening of the ends of the wire-ropes is made clear. The dimensions of the plates are 4' 2" × 3' 8", with a thickness of metal of 8" in the centre and 3" around the sides, strengthened by ribs. A cable being composed of nineteen ropes or smaller cables (twisted or not), there are nineteen corresponding holes for their reception. These holes are conically shaped, the larger opening having twice the diameter of the smaller one. Some of the large openings are elliptically shaped, in order to gain room. That face which serves as an abutment for the channel-bars, composing the arch, is to be planed off to admit of a fair bearing. The weight of the plate is supported by its upper flange, which rests upon the ends of the upper channel-bars. A further support is provided by two cast-iron posts which fit against the face of the end truss-posts and are bolted to it. It remains now to convey a clear idea of the manner of securing the ends of the small cables within the plate. This is done by spreading apart the different wire-strands and wires which compose a rope, and inserting a number of iron points between them in such a manner that the whole span inside of the conical hole is filled out solid, Fig. 1440. By these means the end of the rope is swelled out into a conical lump 8 in. long, which cannot slip out of the plate without bursting it.

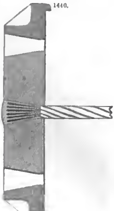
It is important that these plates should be cast of the strongest metal—good, strong, cold-blast charcoal metal—such as is used for the manufacture of good car-wheels. The points driven in between the wires may vary in length as well as in thickness. First drive in a number of long ones, 6 to 8 in. in length, about ½ in. in diameter at the thick end and gradually reduced to a point, filed off round and dipped in linseed oil before driving, to make them go easy. Also pour

some linseed oil between the wires, to make them smooth. The oil will prevent the staving up of the wires and facilitate the process. After filling up the remaining spaces with shorter and thinner points, then cut off the ends of the wires projecting over the plate even with it, one after another, and bend their ends to a right angle over the ends of the points. This being accomplished, apply a clay mould around the whole, so as to form a raised rim, and pour in melted lead, which will fill all the remaining interstices and make the whole one compact mass. After removal of the mould apply the hammer to make the lead solid, file it smooth, and round it off a little to give it a finish. To insert the ends of the ropes without trouble, it is necessary to wrap them well with annealed wire; and as the end is forced in, the wrappings will be pushed back.

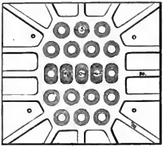
1439.



1440.

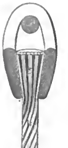


1441.



Stays.—Similar to the plan just described is the method of fastening the ends of the stays: with this difference—that each stay-rope has a cast-iron socket for itself. This socket, together with the wrought-iron stirrup which holds it, is represented by Figs. 1442 to 1445. The stirrup is made of round iron $1\frac{1}{4}''$ diameter, and varies in length to suit the inclination of the stay. Where the stirrup passes around the floor-beam, a small segmental casting, forming a seat for the stirrup, is fitted against the beam, for the purpose of giving the stirrup a fair bearing. The screws must be long enough to tighten the stays. To preserve their straight lines, they are connected with the suspenders by wire wrappings.

1444.

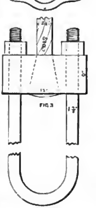


1442.

It will be noticed that the stays as well as suspenders, together with the cables, are all suspended in one vertical plane which passes through the centre of the 2-ft. space left open between the two rows of truss-posts. The cross-bars connecting each pair of posts are not to be put up until the stays, cables, and suspenders have been placed and fixed in their position.

At the ends of the trusses four small stays may be noticed, which are provided for the purpose of guarding against vibrations at those points, and also to add to the supporting strength. The upper and lower chords being necessary, independent of support; their strength is thereby brought into play. Accordingly as much tension is thrown upon the stay-ropes as the resistance of the chords will permit. The ropes are double, and their diameter varies from 1 to 2 in.

Cables.—There are two wire-cables, one on each side, suspended in vertical planes between the double rows of truss-posts. Each cable is composed of 19 wire-ropes of $2\frac{1}{4}$ in. diameter. The maximum tension of the two cables at the tower is 764 tons, and at the centre of the main span 696 tons. Dividing 764 by 36, we have the tension of each rope equal to $20\frac{1}{10}$ tons; and, allowing

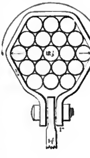


1443.

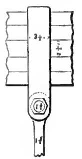
1445.

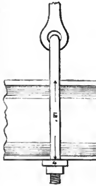
six times the strength, we have for the ultimate strength of each rope 120·6 tons. Although the tension of the cables is less in the centre, the same section and strength are observed throughout. A chain may be tapered, but it would be false economy to attempt it in a cable. Fig. 1446 shows a section of one cable on a larger scale. The nineteen ropes are suspended in five layers, and care must be had to preserve the relative position of each layer, as well as of each individual rope, throughout its length, so that the union of the whole nineteen will in section form a hexagon. The suspenders being attached every 10 ft., a strap is laid around the cable, and screwed up tight, to preserve its form. These straps should be made by about three different patterns, to suit the inclination of the different parts of the cables. When putting them on, they are heated in a small hand-forge, and a strip of sheet iron is laid over the cable to prevent heating the wire. After closing, they are cooled by pouring on water.

1446.

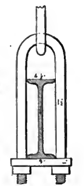


1447.





1448.



1449.

To keep snow and wet out of the cables, they should be protected by a half-circular cover made of tin, secured to the straps by small wire wrappings. This is indicated in Figs. 1446 to 1449.

A uniform tension of the ropes is easily obtained by suspending them parallel to each other in level layers, and in close contact. First secure one end in the anchor-plate; then adjust the rope in the saddles with a proper deflection at the lowest point of each span. Then pass the other end through the other plate, open the seven strands, and pass the centre one through a conical tube 7 in. long, wide enough at the small end to admit the strand, and at the other end enlarged to double the diameter. The whole rope being a little longer than necessary, say 1 to 2 ft., the centre may be fastened temporarily or anchored back, preserving at the same time its central position in the hole. By slackening or tightening this centre now, the position of the rope in the cable may be adjusted. When right, drive the hollow tube into the anchor-plate some distance, and at the same time insert a number of large points, and drive them all in uniformly. When all the large pins are in, the centre may be released, and the untwisted wires may be cut off the right length. Then insert thinner points in the centre tube, and fill it, and complete the whole. To give a support to the anchor-plate, it is of course necessary to put up the truss-posts as far as they rest on the abutment, and to secure them temporarily by timber-bracing. And it will also be necessary to provide for a temporary anchorage of the anchor-plate itself before the arches are put up. This may be done by extending a few wire-ropes from the anchor-plate and posts to the next pier or abutment, and secure them; and if this masonry is not strong enough, a temporary anchorage of timber and stone must be put on shore, of sufficient strength to resist the pull of the cables. The same wire-ropes which are to be used for the abutment-stays and for the storm-cables, and which are to be delivered in long coils, may be advantageously used for this temporary anchorage with very little loss or waste.

The tension of each full cable, resulting from their weight when freely suspended, will be 63 tons; and this has to be fully met and supported. By the use of a few railroad bars laid across the posts above and below the anchor-plates, and by passing stirrups or chains around them, the anchor-ropes may be attached. On the shore they may be fastened to similar bars, placed in an excavation, the bars to be secured to a rough framework of timber and plank, and this may be kept in its place by earth, gravel, stone, and other heavy material: it may also be assisted by braces. Piles may also be driven to increase the resistance of this temporary anchorage.

In order to put up the arches and other parts of the superstructure, a temporary platform and footway will have to be suspended. As to the cables, a light foot-bridge under each will be all-sufficient, and the same anchorage which answers for the main cables will answer for the foot-bridge cables. It should be observed here, that the temporary anchorage should be made strong enough to resist a pressure of about 400 tons, because this much tension may be produced by the cables while erecting the superstructure.

While putting the ropes in the cables, they should receive another coat of durable paint. Allowance must be made for the stretch of the cables. All wire will stretch, whether made of steel or iron. A No. 8 steel wire of good quality, capable of supporting a weight of 3000 to 3400 lbs., and 5 ft. long, will stretch 1 in. before breaking. After being taxed with a full load for some time, the stretch of the cables will cease, because the material will have assumed a permanent set. After this, no more elongation will take place. The deflection of the cables in the main span, after the

wire has attained a permanent set, is to be 60 ft. An allowance of 1 to 2 ft. should be made for settlement. If the cables are well made, 1 ft. will be enough; but if poorly made, 3 ft. may not be sufficient. To be more explicit, the cables should be suspended with a deflection of, say 58 ft., if well made, and if not, 56 to 57 ft. will be safer.

In order to make the cables bear their allotted portion, the suspenders have to be screwed up repeatedly after full trains have passed over the work. The permanent set of the cables will make itself felt distinctly if attention be paid to it. On the other hand, it would be wrong to tax them too much, and thereby relieve the arches to an undue degree. A proper adjustment may at first sight appear to be impossible, or at any rate attended with great difficulty. But if the directions given here are strictly carried out, this adjustment may be readily accomplished.

The weight of the superstructure which is to be borne by the cables of the main span is 290 tons. The number of suspenders is 96, and therefore the weight borne by each is $\frac{290}{96} = 3\cdot02$ tons. Each suspender being attached to a stirrup which has two screws, the weights to be borne by each single screw will be $1\frac{1}{2}$ ton, or 3000 lbs. Now practise a few intelligent men in raising a weight of 3000 lbs. by such a screw, using a screw-wrench of a certain length, say 18 in. The screws should be well cut, so as to run easy and smooth. No stirrup should go into the work without having the screws well examined, well cleaned, run smooth, and oiled.

The handles of the wrenches should be just long enough to require the average strength of a man's arm. To make this operation still more certain, the wrench may be tested by a suspended weight, so that the men can compare their strength with the actual weight. Much depends upon the cut of the screws; with good uniform threads, every suspender must be brought to a fair and equal bearing.

The length of the suspenders being calculated, they are manufactured accordingly, and put in place; but the theoretical length will never exactly agree with the actual length, and the difference is made up by screwing. The above remarks on suspenders will equally apply to the stays. The ultimate strength of each stay is 100 tons, and they are calculated to bear an ultimate tension of $\frac{1}{5}$, or 20 tons, caused by the superstructure and a maximum load. Now, the proportion of weight of superstructure to that of maximum load which falls upon the stays is as 150 : 174, as will be seen in the Table of relative loads; consequently they may be screwed up to a tension of about 9 tons, and this is accomplished with a wrench of about $3\frac{1}{2}$ to 4 ft. long.

After the cables have obtained their permanent set, and the suspenders and stays have been adjusted, no more attention need be paid to this part of the structure. The relative supporting power of the cables, stays, and arches will remain unaltered, they will not undergo any further change. And as changes of temperature will influence the aches as well as the cables alike, no strife between the different members can arise on that account.

The curve formed by a cable when freely suspended and not loaded, will be that of a catenary, because the weight of a unit of cable is supposed to be the same throughout its length. But with a weighty horizontal platform suspended to the cables their curve is changed, and will be found to correspond more to a parabola than to a catenary. The suspenders may accordingly be calculated for a parabola, but it will be found in practice that they vary, and sometimes considerably, from both curves. The screws at the ends of the suspenders will be the means of adjustment. But another change in the curvature of the cables will take place when the stays are tightened and begin to relieve the cables at those points. They will then be lowered in the centre and raised near the towers. Allowance must be made for this in the length of the suspenders, so far as the stays extend.

Suspenders.—The maximum weight borne by the 96 suspenders of the middle span is 626 tons. Each suspender, therefore, has to support $6\frac{52}{100}$ tons. Allowing seven times the strength, we want for the wire-rope suspenders an ultimate strength of 45 tons, or $1\frac{3}{4}''$ diameter rope.

Figs. 1444, 1445, show a wire-rope suspender, both ends fastened in wrought-iron sockets, and the lower socket attached to a stirrup which passes around the floor-beam. Figs. 1447 to 1449 exhibit one of the short, solid suspenders hung to the cable-strap and to the stirrup below. The rods are $1\frac{3}{4}''$ diameter, and the stirrups $1\frac{1}{2}''$ diameter. These dimensions may appear extravagant, but when it is considered that under a heavy passing load, every single suspender is taxed more than its general proportion, this large allowance will be justified.

Chords.—The arrangement of the upper and lower chords is plainly exhibited on the plans. Figs. 1436, 1437, show it more particularly. The 9-in. channel-bars composing them extend from end to end without interruption. The lower chords are not plated underneath at any point. This is not wanted on account of strength, and their lateral stiffness is amply ensured by the floor-beams, by the plates to which the tie-rods are secured, and by the stay-bolts. Nor are the upper chords plated on top, except in the side spans from the end of the truss to the point where the cable enters. These top plates are $\frac{1}{2}$ in. thick and 50 in. wide. The cross-beams are here placed on top of these plates and riveted to it.

The splicing of the chords is done in the same manner as that of the arches. Whenever a stay-bolt is applied to the chords it is passed through a gas-tube, which is cut off on the lathe to the right length, and thus a firm and simple connection is made. In order to meet the thrust of the arches, in excess in the one span, while no load is on the other, a section of 60 sq. in. was found to be necessary for the lower chords. The horizontal action of the stays at the tower is compressional only, and does not add to the tensile strength of the arches. The horizontal action upon the chords, which results from the diagonal rods in the panels, is balanced in each panel, and requires therefore but little section.

A section of 6 sq. in. for the channel-bars of the upper chords will be an ample allowance. The same section may be observed throughout the length of chord. It is, however, necessary to make the splices of the lower chords as strong as the channel-bars themselves, so that they may

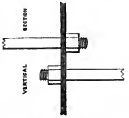
resist a full tensile strain, which may be brought upon them by the arches when the spans are unequally loaded.

Posts.—The posts are of the beam section, and 9 in. wide or deep; Figs. 1450, 1451, exhibit sections on a larger scale: the weight is 25 lbs. a foot. All the posts are 22 ft. long, except those in the centre span, which vary from 22 to 44 ft.

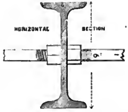
Each truss consists of two rows of posts planted 24 in. apart, in which open spaces the cables, stays, and suspenders are freely suspended. They are firmly connected by horizontal bars 1⅝ in. square: the ends of these bars are spread out so that they will give room for 4 rivets of ⅝ in. diameter, to be fastened upon the flanges of the posts. Each cross-bar is therefore held by 8 rivets.

In order to increase the lateral stiffness and stability of the trusses, the intervening space between the posts may be enlarged to 30 or 36 in.; and the connecting-bars should then be 2 in. in place of 1⅝ square. The vertical stiffness of the posts in the direction of the trusses is aided by horizontal connecting-bars at the centre. These bars are only 1 in. diameter, pass through the web of the posts, and are simply screwed up by a nut at the end, as is shown, Figs. 1450, 1451.

1450.



1451.



1452.

By tightening these bars uniformly, the lateral position of the posts is secured and vibration prevented. This provision is very necessary, on account of the great length of the posts.

Arches.—The arches are formed of channel-bars, Fig. 1452. The posts being 20 ft. apart, the channel-bars are rolled of the same length so that the splices all come upon the posts. It will be noticed that the connections with the splicing-plates are made with screw-bolts, and not with rivets. This will greatly facilitate the putting up and adjustment of the arches. One of the practical difficulties in putting up such work is to make the ends meet, and to make a tight and workmanlike fit, so important in arches and chords. This difficulty is much increased by great variations of temperature, and hence the importance of using screw-bolts in place of rivets. The bars may at first be put together loosely and without any tight fit, by using small bolts temporarily, which are to be removed after the joints are brought to a close. Each pair of splicing-plates, opposite each other, is connected by six bolts of ⅞ in. diameter, or three on each side of a post: on being drawn tight, they embrace them solid and firm. In order to screw these up tight, they must not be enclosed in tubes. The remaining four bolts, on the other hand, are passed through gas-tubes 9 in. long and 1 in. wide, which therefore preserve the distance between the channels and serve as stay-bolts. Two small plates 4 in. × 7 in. × ½ in. thick are riveted to the post and fitted between the channels. Two of the channels are therefore firmly enclosed between these plates and the brackets. To add still further to the stiffness of the splices, the cross-channels which connect the two lines of trusses are filled in between and firmly bolted to the posts, while at the same time their flanges are riveted to the flanges of the arches. When the latter cross the posts obliquely, the cross-channels have to be heated and swedged in a block by pressure, so as to fit the oblique section. By using wedges of different shapes to correspond to the inclination of the arch, one press or one pair of blocks or dies will do for the whole. If the cost of such a press is objected to, the flanges of the cross-channels may be cut out and the stem only bolted to the post.

So far as the arches rise above the upper chords in the central span, the upper channels are connected by a top-plate of ½ in. thick riveted to the upper flanges. Laterally, between the posts in each panel, the arches are again connected by four channels of 50 in. length each, and also by stay-bolts passing through gas-tubes.

Where the arches rise above the upper chords, the channels forming the latter are cut out and planed off to the proper level to make a good fit. Splicing-plates are then riveted over the joint, and the respective flanges are also connected by rivets. At the same time a plate of 4 ft. long by 2 ft. wide and ½ in. thick is riveted down on top, so as to cover all the joints. The depth of each arch is 41 in., and its width 4 ft.

Considered as a straight girder freely spanning a distance of 60 ft., this combination would be stiff enough for railroad traffic. But its inherent stiffness is not calculated to serve as a supporting power, but to resist lateral deflection like a column. A round column is, of course, the best geometrical section for gaining lateral strength. But a columnar section in wrought iron for the purposes of an arch, presents many difficulties and objections. What would be gained in section would be more than lost in reduced strength of framing.

The great facilities of construction which the plan before us offers, must not be underrated. And when we consider the small section of wrought iron that is needed to make the arches effective, this plan will compare favourably with other plans heretofore attempted. The arches

of the Coblenz Bridge over the Rhine are 308 ft. wide in the clear. Each rib is 10 ft. 6 in. deep, with upper and lower flanges. The flanges of the centre rib are 3 ft. 2 in., and those of the outer ribs 2 ft. 2 in. wide. These arched ribs have been treated as flexible trusses, consequently the upper and lower flanges have been graduated like chords, with the greatest section in the centre. The upper and lower chords are connected by posts and diagonal braces. This work is considered a model work; it is well proportioned and possesses ample strength. The stiffness is in the arches alone, and no attempt has been made to increase it by spandril-bracing. Its rigidity is owing, in a great measure, to the placing of the floor *below* the crown of the arch.

The question arises, whether flanged arches with greater inherent stiffness would not be better adapted to the Parabolic Truss, than the arches here designed? So far as simple supporting power is considered, under the action of uniformly-distributed loads there would be no difference between the two plans. As regards stiffness, under the action of variable loads, however, the plan here proposed, with its great depth of trussing, will produce more rigidity, with the same amount of material expended, than would result from flanged arches. This view will apply with still greater force, when the arch descends below the lower chords. The depth of ribs in the Coblenz Bridge is 10 ft. 6 in., and the clear span 308 ft. (Prussian measure), a proportion of about 1 in 30. This depth would evidently be entirely too small for a straight girder of 308 ft. span, but it would be enough for a span of 100 ft.

In the Coblenz Bridge, the floor intersects the girders or ribs at the lower chord, and we may therefore consider the whole arch, so far as stiffness is concerned, as divided into three equal parts. The central part is stiffened by the floor, and the spandrils are stiffened by the posts which support the floor. But no further bracing has been attempted in the spandrils, on account of contraction and expansion; but this appears to be a defect, because an expenditure of very little additional material would have greatly added to the rigidity and strength of the work without materially interfering with contraction and expansion. It must be remarked, however, that the leading idea in the design of this celebrated viaduct was to interfere with the arches as little as possible, and to depend upon their own inherent stiffness, so that the ribs should be at liberty to accommodate themselves freely to variations of temperature. This same view led to the planning of the *pivot* skew-backs; but this defect has been corrected since by making the bearings of the skewbacks all solid.

When we omit the arches in our plan, considering the structure as a pure suspension-bridge, and compare its stiffness with that of the Niagara Bridge, we discover that the truss here designed possesses ample stiffness for all railroad purposes. The Niagara trusses are only 18 ft. high; those before us are 22 ft., with a span of 500 ft.; while the Niagara span is over 800. In the Niagara Bridge the truss-posts are 6 ft. apart; here they are 20 ft. The Parabolic Trusses being double, there are four diagonal rods of 1½ in. diameter in a panel of 20 ft., while there are two rods of 1¼ in. in a panel of 5 ft. at Niagara. On the other hand again, the Parabolic Trusses are all of iron and have comparatively very strong chords, while the Niagara framing is of wood, with light chords, which are, however, very materially assisted by the floors and the central girders, which latter distribute the weight of concentrated loads.

Roebling concludes that the trusses before us (without including the feature of the arch), will be quite as stiff as are the Niagara trusses.

When compressive action takes place in chords and arches, experience has demonstrated that 4 tons of 2000 lbs. each, or 8000 lbs. a sq. in. maximum pressure, is as much as soft, puddled iron should ever be taxed. But this resistance depends so much upon lateral conditions that the above allowance of 4 tons would scarcely be safe for single arches *not* assisted by cables. But the great feature of safety in the Parabolic Truss is the cable. The arch is only an auxiliary to the cable. With ordinary loads, the cables and stays will support the greatest part of the strains; and the more they are strained the greater their tendency to maintain their vertical positions, and to assist the arches in preserving their true alignment. *Lateral flexure is the great danger to arches.* The more jointed and articulated the system is, the greater this danger. Now, these considerations must be taken into view when deciding upon the choice of material for the arches. The question of steel or iron is of course a question of comparative estimate. But if, for instance, we allow 8000 lbs. maximum compression for iron, and 12,000 lbs. for a mild steel, and the steel arch costs the same as the iron arch, both possessing the same supporting strength, then the iron arch should be preferred to the steel arch, for the following reasons:—

1. The greater section of the iron arch will ensure greater lateral stiffness than can be obtained from the diminished section of soft steel.

2. The greater weight of the iron structure adds to its stability under the action of variable loads in direct proportion to its superior weight when compared with steel. Vibrations caused by fast-moving trains will be felt more by the lighter structure than by the heavier one.

One of the best features of the Parabolic Truss, as here designed, is, that the principal members of this system are nearly uniform in their sections, and that they are not alternately exposed to such opposite strains as compression and tension in succession.

The cables and stays experience tensile strains only, while the arches are exposed to compressive action alone. This feature will add much to the lifetime of the structure.

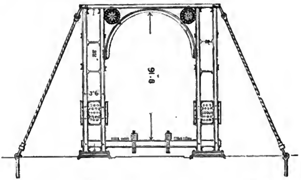
An objection may be raised to the parabolic form of the arches, because of the variation of bevels at the joints. The difference, however, between the segment of a circle and the parabolic curve, with the proportions here observed, is so small, that the substitution of the one for the other will not have the slightest practical influence. It will therefore facilitate the work, to cut all the joints to the same bevel for a circular arch. Respecting the cables, however, the suspenders should be calculated for a parabolic curve.

Floor-beams.—The beams supporting the railroad track are 5 ft. apart and 12 in. deep, and weigh 40 lbs. a lineal foot. If manufactured of good iron, a load of 23 tons, equally distributed, will not produce a sensible deflection, and a load of 15 tons on the two rails will be within its elastic limit. The lower flange of each beam is riveted to the upper flanges of the channel-bars com-

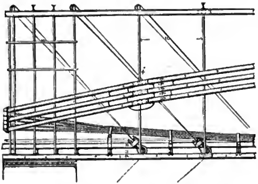
posing the chords, sixteen rivets of $\frac{3}{4}$ in. diameter for each beam. This forms a very stiff horizontal connection of the opposite chords, and renders all further diagonal bracing unnecessary. This stiffness is further increased by the 9-in. girders, running lengthways underneath, riveted to the beams, and connected with the timber stringers, the rails, and the breachings by stirrups 2 ft. 6 in. apart.

The upper joints, connecting the arches and upper chords, are channels 7 in. depth, of a light section, one on each side of a post bolted to it and riveted to the flanges of the arches and chords. Fig. 1453, which is a section on the abutment, fully explains the details. So far as the upper chords in the side spans are plated, the joints are of 7-in. beam section in place of channels, their lower flanges riveted to the plates, Figs 1454, 1455.

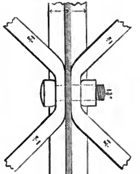
1453.



1454.



1455.



Diagonals in Panels.—The object of the panel-rods is to impart stiffness, and to spread any concentrated pressure over a large extent of truss. In the centre of the main span, the pressure upon any point is spread by these rods over 4 panels, or 80 ft. of length of truss. For every row of posts there is a plane of diagonals; consequently there are 4 lines, each rod $1\frac{1}{4}$ in. diameter, with screw-ends proportionally enlarged.

Fig. 1454 explains how two diagonals are joined in one, and how they are bolted to the stem of the post, between the upper chords.

It will be noticed that these rods all radiate toward central screw-rings, for the purpose of screwing them up to a proper tension, and thus to impart stiffness to the framing.

Any load upon any one point will make an impression upon 2 to 3 floor-beams, and 16 rods, of $1\frac{1}{4}$ in. diameter each, will be brought into service, and distribute the weight over a large extent of truss.

Storm-cables.—The arrangement of the storm-cables is fully explained by an inspection of Figs. 1428, 1429. Two wire-ropes of an ultimate strength of 100 tons each are suspended below the floor in such a manner as to form parabolic curves. By this plan no longitudinal strains are thrown upon the superstructure. All the strains are directed upon the floor-beams, and are regulated by screw-bolts to give the cables a proper tension. The horizontal deflection of these cables in the centre span is 41 ft., or about $\frac{1}{13}$ of the span, and therefore the coefficient of tension is 1·70. If we assume now that the force of a high wind should be so great as to produce a uniform horizontal pressure against the structure equal to 20 tons, then the strain on the cable would be $1 \cdot 70 \times 20 = 34$ tons, or about $\frac{1}{3}$ of its breaking strength. This tension might be

increased even to 50 tons without at all endangering the safety of the cables. But little surface is exposed to the wind vertically as well as horizontally.

It is well known that on a structure suspended at a high elevation, the wind exerts more of an uplifting power than of a horizontal action. The uplifting force is amply met by the weight of the structure itself. Estimating the vertical area exposed to horizontal action at 3000 sq. ft. and a pressure of 30 lbs. a sq. ft. applied all over, the aggregate pressure would be 90,000 lbs., and would be met by the strength of the cables. In this calculation no allowance is made for the inherent stiffness of the horizontal framing at the upper and lower chords and the top of the arches.

As has been remarked before, an objectionable feature in the plan before us is the great height of the arches in the centre of the main span, and its tendency to lateral oscillations under the action of fast-moving trains or from the effects of heavy gusts of wind. Where, therefore, a necessity exists to preserve the whole space below the lower chords clear of all obstruction, either a double bridge must be erected at once, the two connected together, or a more effective horizontal bracing must be put up in localities which are exposed to very high winds or hurricanes. This horizontal security can be increased by heavier diagonal ties between the upper chords and arches, by doubling the storm-cables and by adding diagonal bracing. Any amount of security may thus be obtained. It will be noticed that the contractions and expansions of the storm-cables from changes of temperature are not at variance with those of the trusses, because they form one connected whole, and will always move together.

Method of Raising the Superstructure.—A most important question is the practicability, safety, and cost of erecting the superstructure of such large spans as here proposed. Short spans may be raised on temporary scaffolding, one span at a time, with facility and little risk. But the task of putting in place spans of great dimensions in a river which is subject to sudden rises, full of floating *débris*, and with an unstable bed, is formidable, and may in certain stages and at certain seasons become impracticable.

The history of the erection of the 500 ft. span of the Kuilenburg Bridge in Holland has furnished a practical demonstration of the difficulties involved in such an enterprise. Before the entire completion of the large span of that work, a heavy gale sprung up and demolished all the scaffolding, but left the trusses unaffected, their bearing parts having been previously all safely connected. Had this high wind occurred a few days sooner, the whole superstructure would have been thrown down a total wreck.

It may be of interest to notice here the method pursued by the contractor of the Coblenz Bridge (the same who put up the Kuilenburg Bridge) in raising the three arches of that work. The two halves of the arched ribs were completed on shore, then launched and floated on boats to their destination, whence they were raised to their permanent position and connected. The raising was done by a hydraulic press supported on a temporary scaffolding put up in the centre of the span. Arches of a little over 300 ft. may be managed in that way quite successfully and economically. But when the span is doubled, the drawbacks attending this process are also doubled, and it will be wise to consider other methods.

In comparing different plans of raising, the questions of relative economy and of speed of execution are of much less importance than is the question of *safety*. That method should be adopted which ensures absolute safety under all circumstances. Fortunately, the plans of superstructure here proposed, while exhibiting economy and strength, also admit of the safest mode of erection. The Parabolic Truss, as here devised and modified, is a combination of the suspension-cable and of the arch. If, therefore, we suspend the cable first, we may afterward suspend the arch to it, independent of scaffolding, flood, or ice. The whole work may be put up in this manner, without the use of any scaffolding whatever. Should the season and stage of water, however, be favorable to scaffolding, then a few light bends should be used, supported on piles and connected with the suspended platform by hemp-rope lashings, in such a manner that in the emergency of a sudden rise, the lashings may be cut in a few minutes, and the bends allowed to float off without doing any further harm. A few such light scaffold-frames put up, say every 50 or 100 ft., will much assist in preserving the proper level of the suspended platform, and therefore facilitate the joining of the various members of the structure. Those, particularly, who are without experience in suspended structures will find the assistance of bends very useful. But they are not a necessity, only a convenient auxiliary.

After the masonry of the first central pier has been completed, the erection of the wrought-iron shafts composing the tower will be commenced, and the saddles placed on top and secured. On the second centre pier where the superstructure is not to be fixed permanently, but allowed to contract and expand freely, the roller-plates and rollers have to be laid down first, before the erection of the towers can be proceeded with. The same must be done on the abutments. First lay down the roller-plates, then put up the posts, chords, and transverse beams, so far as the masonry furnishes support. Also put up the anchor-plates, and secure these to the posts. It is also necessary to secure the stability of the ends of the trusses on the abutment still further by temporary wooden and iron braces. Great security will be obtained from the lateral wire-rope braces, when put up and screwed tight.

A temporary anchorage will now have to be prepared for the purpose of meeting the strains caused by the cables. The wire-ropes provided for the storm-cables may be used for this purpose.

By making an excavation about 10 ft. deep and 25 ft. long by 25 ft. wide, and driving a few piles in front, using some of the 12-in. iron beams, railroad bars, timber, and stone, a temporary anchorage may be made, which will safely resist a strain of 500 tons.

In order to have the means of regulating the tension of the temporary anchor-cables, and to provide, to a certain extent, for contraction and expansion while engaged in raising, it will be advisable to deflect the anchor-cables a few feet, and anchor them in the centre between the anchorage and abutment to another temporary anchorage, by means of long screw-bolts and stirrups, or by block and tackle. This will afford the means of allowing the anchor-plates to

move forward towards the river just enough to close the arches and chords. Allowance must also be made for stretching the cables.

We have now proceeded far enough to take across the river two of the smaller cables or ropes which are to form parts of the large cables. An easy mode of accomplishing this will be to remove the reel which contains one coil of wire-rope upon the deck of a flat boat or barge, and to mount it upon a strong, well-secured frame, on a spindle which rests on bearings, and is allowed to revolve. Now provide one or two brakes to check and regulate the speed of the revolving reel, and employ a tug to tow the barge across the river, either above or below the line of piers.

The end of the rope should of course be first secured to one of the anchor-plates before starting. On crossing the river, the rope is simply dropped upon its bed. The other end being landed, is now temporarily secured to its anchor-plate, and preparations are made to hook up the rope at the centre piers, and to raise it to the top of the towers. Here it is rested on temporary timber-blocks, which serve as saddles, and are secured alongside of the cast-iron saddles.

After two wire-ropes have been taken across and suspended, their deflection must be adjusted, and they are then further secured to the middle towers by screw-clamps and bolts, to prevent their slipping. The object of these temporary suspension-cables being to facilitate the construction of the main cables, it is advisable to deflect them about 2 to 3 ft. *below* the main cables, so that they will run nearly parallel to them. This being done, light timber-beams or scantling, say 24 ft. long, may be thrown across the two opposite ropes, and lashed to them *from below* by hemp lines at distances of about 4 to 5 ft. apart. This process should commence at the two middle towers, and should be carried on both ways, so that the spans will be equally weighted, and their equilibrium maintained. Planks are pushed forward over the beams and secured by lashings, so that two foot-walks are formed, each about 4 ft. wide, in line of the main cables and underneath. Where these walks are very steep, the planks may be cleated, to secure a better foothold.

Two footways have now been put up, extending across the river from one abutment to the other. To facilitate the crossing of men not used to high elevations, two small wire-ropes $\frac{1}{4}$ to $\frac{3}{8}$ in. diameter may be suspended just above the position of the main cables, and connected laterally every 50 ft. by smaller chords. The men will take hold of these ropes while crossing, and use them as hand-rails.

This being accomplished, we are now enabled to go from pier to pier and to perform work independent of the river. As the stays are placed in the bottom of the saddle, they must be raised first and put in place, allowing their ends to hang down the piers. This being done, the first permanent cable-rope may now be fastened to its anchor-plate at one end, then taken across the river and run off the reel in the same manner as before. These ropes are to be dropped upon the bed of the river, either above or below the piers, always on the side of their respective towers. Whenever a rope has thus been run off, it must be raised and placed upon the saddles before another one is launched on the bed of the river. It is also necessary that each rope should be properly placed and its deflection adjusted correctly before the next one is taken up.

The section of a saddle on Fig. 1437 exhibits plainly the different layers of rope. First, there are four laid down in the bottom, forming the first row; then one is added at each end in the second row. These six ropes are the stays. Next come the three ropes which compose the first or lowest layer in the cable; this is followed by a second row of four ropes; next comes the centre layer of five ropes; next, a layer of four ropes, and then the top layer of three ropes; the whole number of 19, which are in a cable, forming the section of a regular hexagon.

It is all-important that the five different layers should preserve their stratification and their proper level throughout the whole length of cable. To facilitate this operation, strips of canvas or strong cotton sheeting, say 3 in. wide, may be wrapped around each layer, and afterward again removed. Whenever a rope is added, it should be secured at various points by ties of fine annealed wire. The best plan, however, is to introduce short strips of tin, Fig. 1456, which cross each other diagonally, the whole being kept together by temporary wire or hemp strings. After all the 19 ropes have thus been suspended, adjusted, and collected into one cable, strong temporary wire-bands, made of No. 10 annealed wire, must be put around every 10 or 15 ft.; which operation will be greatly facilitated by using iron screw-clamps made in two halves, and fitting the section of the cable.

1456.

Referring to Figs. 1436, 1437, we notice that the lattice-beams which connect the opposite saddles of each tower may be omitted for the present, and that the two ropes for the footwalks may be supported on the cross-beams next below the lattice, which will be about the right elevation for cable-making.

It was remarked that the two ropes suspended temporarily for footwalks are to be laid into the main cables *eventually*. This method is recommended for the sake of economy. But if some more wire-rope is on hand, strong enough for that purpose, then it will be better not to make temporary use of the permanent cable-ropes. It is supposed, however, that there is no spare rope on hand, and in that case two of the cable-ropes are to be suspended for footwalks, one on each side. Now, after the other 18 ropes have been raised and adjusted in each main cable, the cross-beams which support the foot-plank may be suspended to the main cables by simply throwing small manilla ropes over in such a manner that they can be easily removed. This being done with all the beams, the two wire-ropes which supported the foot-planks are now free and may be raised into the saddles, adjusted to their proper levels in the various spans, and both ends secured. After this is done, the manilla suspenders over the main cables are now lifted, one after another, and thrown over the last wire-rope, and again fastened to their respective beams. The cables are now ready for the permanent suspenders and straps. The latter are heated at one corner, so that they may be readily closed and screwed up tight. To prevent injury to the cable, a piece of sheet-iron is laid around it: the strap is then closed and cooled off with water. A small hand-forge may be moved along on the suspended scaffolding for that purpose.

It will be a somewhat difficult task for those not experienced in the construction of wire-cable bridges, to get the cable straps and suspenders properly spaced.

Measurements from the towers being uncertain and the cables movable, no satisfactory adjustment can be effected in this way. But, either by calculation or actual suspension, or both, measure off the actual distances upon a small wire-cord, or upon a single wire. These distances in the suspended cable form the hypothenuses of right-angled triangles, the horizontal base of which is a *constant*, equal to the horizontal distance of the suspenders. The vertical is variable, and is equal to the difference of the lengths of the two adjoining suspenders. These triangles may all be laid off on one board, and the length of the hypothenuses transferred upon the wire-cord and marked by small wrappings made of fine wire, so that they cannot be shifted. This wire line is then suspended alongside of the centre of the cable, and whitelead marks are put upon the latter, which will correspond to the centre of the suspended ropes.

These measurements and marks being correctly made, there will be no further difficulty in spacing the suspenders correctly; their length will come out nearly correct, and the beams suspended to them will be found equally spaced.

The main cables being completed, they should be further secured in their saddles by bolting down those cushions which are to prevent their slipping. A temporary platform must next be suspended below the level of the lower chords, strong enough to support 1 ton a foot lineal. The suspenders being 10 ft. apart, timber-beams 24 ft. long, about 8 × 14, may be suspended to them by means of temporary stirrups, so made that the level may be adjusted. A plank-walk about 5 ft. wide should then be laid down under each cable. The next step is to lay down upon these plank-walks the channel-bars which are to form the lower chords. Care must be had to distribute those bars evenly and uniformly on each side of a pier, and in all the spans at the same time, so that the equilibrium of the cables is not much disturbed. This distribution being properly made, the bars may be connected by bolts temporarily, and partly spliced, but so that the posts can afterward be set up between.

In order to add to the weight of the platform, and increase its stability, the truss-posts should now be distributed uniformly, and laid down alongside of the chords, all over the work. It may also be the proper time to make use of the main-stays, and to attach their ends temporarily to the lower chords, and to the platform. When up, they will not only add to the supporting power, but also to the steadiness of the platform. The whole process of erection will be much facilitated by a narrow track, laid down in the centre of the platform between the two walks, for the support of a few small trucks, on which the bars may be transported from both abutments. With a favourable stage of water in the river, the delivery of materials may also be forwarded by boats moored at the piers and hoisting the bars up, then distributing on trucks.

The work has now so far progressed that we may proceed to put up the posts. There are several methods by which this may be accomplished. One plan is to proceed from the centre piers each way toward the main span and the side spans uniformly at the same time. As soon as one or two sets of posts are up, connect them by the upper chords, and also secure the latter by transverse beams and temporary wooden braces. Next, put in place the panel-rods, which will increase the stiffness of the framing considerably.

While this process of building out from the piers is going on, the level of the platform must be maintained at the same time, by distributing the bars for the posts and chords all along. The weights being uniformly distributed, the level will be preserved, and the steadiness of the platform will also be increased. A few small wire-ropes may likewise be applied below the platform, fastened to the masonry of the piers, to serve as storm-cables, in case of a heavy blow. Before commencing with the arches, the posts and upper chords may be put up through the balance of the spans, the panel-rods put in, the cross-connections made, and the trusses nearly completed.

Changes of temperature, causing expansion and contraction, may be accommodated by placing the lower chords on wooden rollers about 6 in. diameter.

Slight changes will not be noticed; but should great changes take place, and produce considerable contractions and expansions, it will be good policy to provide slip-joints in the chords as well as the arches at various points, and use a few temporary splicing-plates to that effect, or timbers bolted on sideways. No rigid connection should be made at any place: no riveting before the whole structure is up.

It was remarked that the whole superstructure may be put up and completed without the assistance of scaffolding. This can be done, if absolutely necessary. We therefore propose to scaffold one of the side spans, or both, leaving the central span open for navigation. This being done, we may put up the arches in the two side spans, and also put up one transverse iron beam every 20 ft., to give a good, permanent lateral connection to the lower floor. By the completion of the arches of the side spans, the resistance of the anchor-plates will have been much increased.

One half of the bents under the side spans may now be removed with safety, and put under the spring of the arches in the central opening; and as much material may also be distributed over the platform of the central span as will be necessary to balance the side spans. By this distribution we shall maintain the equilibrium of the cables. The thrust of the arches in the side spans will be fully met by the lower chords, which should be completed; so that it may be safe to remove all the bents from under the side spans and put them up in the centre opening. This being done, the closing of the arches in the centre is now to be accomplished, and the trusses may be sufficiently completed to render a further support by scaffolding unnecessary.

If, during the process of erection, a sudden flood should occur, or floating masses of ice endanger the safety of the scaffoldings, the latter should be watched day and night, and cut loose if necessary. This may cause some delay, but no further damage.

If the spring of the arches descends below the lower chords, the raising of the superstructure will be easier; and this plan should always be adopted if possible.

Statement of the Strains in the different members of a Trussed Girder Bridge of 300 ft. span in the clear.—This iron truss alone weighs 0·85 ton a ft., and is proportioned to sustain its own weight

PANELS.

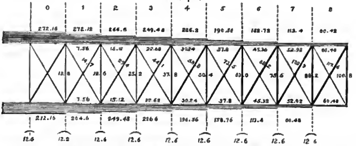
		0	1	2	3	4	5	6	7	8	Total Weight of 9 Panels.	Total Weight of 8 Panels.	Aggregate.
	Weight and load, a panel, for one truss	Tons. 12·6	Tons. 12·6	Tons. 12·6	Tons. 12·6	Tons. 12·6	Tons. 12·6	Tons. 12·6	Tons. 12·6	Tons. 12·6			
2 Tie-rods ..	Tension	0	14·7	29·4	44·1	58·8	73·5	88·2	102·9	117·6			
	Sq. section by calculation	0	2·94	5·88	8·82	11·76	14·70	17·64	20·58	23·52			
	Weight a ft.	0	9·88	19·76	29·64	39·51	49·39	59·27	69·15	79·03			
	Length in ft.	0	35	35	35	35	35	35	35	35			
	Weight in lbs.	0	345·8	691·6	1037·4	1382·8	1728·6	2074·5	2420·3	2766·1	12,447·1	12,447·1	24,894·2
1 Counter-rod	Sq. section allowed ..	1·75 sq. in. / 1·75 sq. in.	1·75	1·75	1·75	1·75	1·75	1·75	1·75	1·75			
	Weight a ft.	5·9 / 5·9	5·9	5·9	5·9	5·9	5·9	5·9	5·9	5·9			
	Length in ft.	35	35	35	35	35	35	35	35	35			
	Weight in lbs.	206·5 / 206·5	206·5	206·5	206·5	206·5	206·5	206·5	206·5	206·5	2,065	1,652	3,717
2 Posts ..	Compression	12·6	12·6	25·2	37·8	50·4	63	75·6	88·2	100·8			
	Sq. section by calculation	3·15	3·15	6·3	9·45	12·6	15·75	18·9	22·05	25·2			
	Sq. section allowed ..	12	12	12	12	12·6	15·75	18·9	22·05	25·2			
	Weight a ft.	40	40	40	40	42·3	52·9	63·5	74·1	84·7			
	Length in ft.	30	30	30	30	30	30	30	30	30			
	Weight in lbs.	1200	1200	1200	1200	1269	1587	1905	2223	2541	14,325	14,325	28,650
Lower chords	Tension	272·16	264·6	249·48	226·8	196·56	158·76	113·4	60·48	3·67			
	Sq. section by calculation	54·432	52·92	49·896	45·36	39·312	31·752	22·68	12·096	0·734			
	Sq. section allowed ..	54·432	52·92	49·896	45·36	39·312	31·752	22·68	18	18			
	Weight a ft.	182·9	177·8	167·6	152·4	132·1	106·7	76·2	60·5	60·5			
	Length in ft.	18	18	18	18	18	18	18	18	18			
	Weight in lbs.	3292·2	3200·4	3016·8	2743·2	2377·8	1920·6	1371·6	1089	1089	20,100·6	16,808·4	36,909
Upper chords	Compression	272·16	272·16	264·6	249·48	226·8	196·56	158·76	113·4	60·48			
	Sq. section by calculation	68·04	68·04	66·15	62·37	56·7	49·14	39·69	28·35	15·12			
	Weight a ft.	228·61	228·61	222·3	209·6	190·5	165·1	133·4	95·3	50·8			
	Length in ft.	18	18	18	18	18	18	18	18	18			
	Weight in lbs.	4114·9	4114·9	4001·4	3772·8	3429·0	2971·8	2401·2	1715·4	914·4	27,435·8	23,320·9	50,756·7

Total aggregate weight	144,927
Add one-half the additional weight of floor-beams, rails, cross-bracing, and so on	93,836
Add one-half the extra items—rivets, bolt-heads, nuts, splicing-plates, and so on	21,337
Total weight of one-half the bridge, or one line of truss	260,100 lbs.
Weight of whole bridge = ...	260·1 tons.

and a moving load of 1100 lbs. The wire cables support a moving load of only 1900 lbs. a ft., Fig. 1457. Tension allowed in iron is 5 tons the sq. in. The compression allowed is 4 tons the sq. in. Panel = 18'.

1457.

306 ft. span.

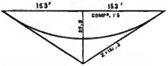


In the foregoing estimate, we have taken the weight on the bridge at 1·4 ton a ft. run. The weight of the structure itself is $\frac{260 \cdot 1}{306} = 0 \cdot 85$ ton a ft. run. The bridge will therefore support, in addition, a moving load of $1 \cdot 4 - 0 \cdot 85 = 0 \cdot 55$ ton, or 1100 lbs. a ft. run.

	lbs. a ft.
Moving load	1900
Top plate	490
Cable	123
Suspender	28
Total weight supported by cables ..	2541

1458.

Steel Cables.



	Tons.
Total weight for whole bridge = 2541 lbs. × 306' = 777,546 lbs. = ...	388·77
Tension in cable, 1·58 × 388·77 tons = ...	614·25
Compression, Fig. 1458, in upper chord due to the cable = 1·5 × 388·77 tons =	583·16

The cable being much smaller in this example than in the previous one, each will consist of only seven ropes: and taking the maximum tension allowed as before, at 5 tons a pound a ft., we have the strength of one rope = $\frac{614 \cdot 25}{14} = 43 \cdot 88$ tons; and the weight a ft. of such a rope is $\frac{43 \cdot 88}{5} = 8 \cdot 78$ lbs. The diameter of this rope is $2\frac{3}{16}$ in., and the diameter of one cable 7 in.

Compression.—The section required in the top plate is $\frac{583 \cdot 16}{4} = 145 \cdot 79$ sq. in. Weight a ft. $= 145 \cdot 79 \times 3 \cdot 36 = 490$ lbs.

Some of this weight will be thrown upon the channel-bars, as in the previous case.

The heaviest section of channel-bar is 56 sq. in., equal to 142 lbs. a yard.

The section required for one top plate is $\frac{145 \cdot 79}{2} = 72 \cdot 895$. Hence we have left for the top plate $72 \cdot 895 - 56 = 16 \cdot 895$ sq. in.

In order to keep the channel-bars of a uniform section throughout, we will add to this top plate the varying sections of upper chord, required by the structure alone, in the calculation above. The following Table shows how this is done; the sixth line gives the number of sq. in. of section required in the top plate in each panel.

Table of Sectional Area of Top Plate in each Panel.

Number of Panels.	0	1	2	3	4	5	6	7	8
Total section of one top plate	72·895	72·895	72·895	72·895	72·895	72·895	72·895	72·895	72·895
Section required for upper chord of structure	68·040	68·040	66·150	62·370	56·700	49·140	39·690	28·350	15·120
Aggregate section ..	140·935	140·935	139·045	135·265	129·595	122·035	112·585	101·245	88·015
Deduct assumed section of channels ..	56·000	56·000	56·000	56·000	56·000	56·000	56·000	56·000	56·000
Leaves for section of top plate	84·935	84·935	83·045	79·265	73·595	66·035	56·585	55·245	32·015
	in. in.	in. in.	in. in.	in. in.	in. in.	in. in.	in. in.	in. in.	in. in.
Dimensions of top plate	42 × 2·02	42 × 2·02	42 × 1·98	42 × 1·88	42 × 1·75	42 × 1·57	42 × 1·34	42 × 1·08	42 × 0·76

Recapitulation of whole Weight.

	lbs.
Tie-rods, counter-rods, posts, upper and lower chords on one side	144,927
Additional weight on one side	93,836
Extra items	21,337
Weight of top plate on one side, 72·895 sq. in. × 3·36 lbs. = 245 lbs., and 245 × 306 = ...	74,970
Cable = 8·78 lbs. × 7 = 61·5 × 312 ft. = ...	19,188
Suspenders = 14 × 306 = ...	4,284
One-half weight of whole structure	358,542 lbs.
Total weight of the entire structure	358·542 tons.

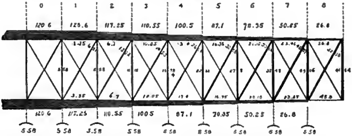
$$\text{Weight a foot} = \frac{358{,}542}{306} = 1\cdot171 \text{ ton.}$$

Statement of the Strains in the different members of a Trussed Girder Bridge of 300 ft. span in the clear.—The iron truss alone weighs 0·62 ton a foot, and is proportioned to sustain only its own weight, while the moving load of 3000 lbs. a foot is supported by wire cables, Fig. 1459.

The tension allowed in iron is 5 tons to a sq. in. The compression allowed is 4 tons to the sq. in. Length of one panel = 18 in.

1459.

306 ft. span.



In the foregoing estimate we took the weight of the bridge at 0·62 ton a foot run. This agrees with the result here obtained, since 0·62 × 306 = 189·72 tons.

Let us now put in a pair of steel cables to support, 1st, the moving load: 2nd, the weight of the top plate required to resist the compression due to the cable; and, 3rd, the weight of the cables and of the suspenders.

	lbs.
Moving load	3000
Top plate	771
Cable	193
Suspenders	36
Total weight on cables a foot run ..	4000

	Tons.
Total weight for whole bridge, 4000 × 306 = ...	612
Tension in cable = 1·58 × 612 tons = ...	967
Compression in upper chord due to cable = 1·5 × 612 tons = ...	918

The ultimate strength of good steel cables is 25 tons a lb. the foot, which is equivalent to 176,000 lbs. a sq. in. solid wire-section; the maximum tension allowed is 5 tons a lb. to the foot. We have two cables, one on each side, each containing nineteen wire-ropes. Hence the strength of one rope is $\frac{967}{38} = 25\cdot45$ tons; and the weight a foot of such a rope is $\frac{25\cdot45}{5} = 5\cdot09$ lbs. a foot. The diameter of this rope is 1·7 in., and the diameter of one cable of nineteen ropes is 8½ in.

Compression.—The section required in the top plate is $\frac{918}{4} = 229\cdot5$. Weight a foot = 229·5 × 3·36 = 771·0 lbs.

In place of putting all this section into a plate, it is better to divide it by increasing the section of the channel-bars in the upper chord somewhat; especially since the sections of channel-bars obtained in the calculation above were so small that they could not be executed in practice. Let us increase the sections of the four channels in one upper chord to 56 sq. in., which is equal to 142 lbs. a yard for each channel-bar, the heaviest section rolled. The section required for one top plate is $\frac{229\cdot5}{2} = 114\cdot75$ sq. in. Hence we have left for the top plate 114·75 − 56 = 58·75 sq. in.

In order to keep the channel-bars of a uniform section throughout, we will also add to this top plate the varying sections of upper chord, required by the structure alone, in the calculation

PANELS.

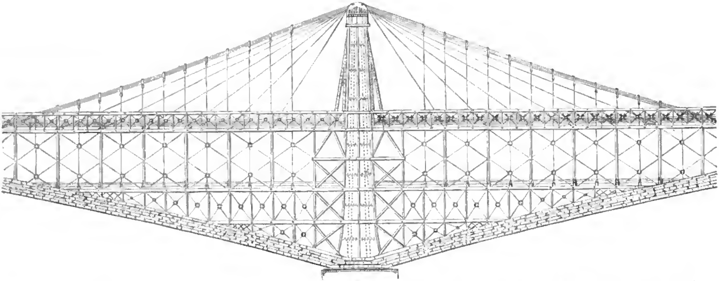
		0	1	2	3	4	5	6	7	8	Total Weight of 9 Panels.	Total Weight of 8 Panels.	Aggregate.
		Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.			
	Weight a panel for one truss	5·58	5·58	5·58	5·58	5·58	5·58	5·58	5·58	5·58			
2 Tie-rods ..	Tension	0	6·51	13·02	19·53	26·04	32·55	39·06	45·57	52·08			
	Sq. section by calculation	0	1·302	2·604	3·906	5·208	6·510	7·812	9·114	10·416			
	Sq. section allowed ..	0	2	2·604	3·906	5·208	6·510	7·812	9·114	10·416			
	Weight a ft.	0	6·72	8·75	13·12	17·49	21·87	26·25	30·62	35·0			
	Length in ft.	0	35	35	35	35	35	35	35	35			
	Weight in lbs.	0	235·2	306·3	459·2	612·2	765·5	918·8	1071·7	1225	5,593·9	5,593·9	11,187·8
1 Counter-rod	Sq. section allowed ..	1½ / 1½ sq. in.	1½	1½	1½	1½	1½	1½	1½	1½			
	Weight a ft.	5·04 / 5·04	5·04	5·04	5·04	5·04	5·04	5·04	5·04	5·04			
	Length in ft.	35 / 35	35	35	35	35	35	35	35	35			
	Weight in lbs.	176·4 / 176·4	176·4	176·4	176·4	176·4	176·4	176·4	176·4	176·4	1,764	1,411·2	3,175·2
2 Posts ..	Compression	5·58	5·58	11·16	16·74	22·32	27·9	33·48	39·06	44·64			
	Sq. section by calculation	1·395	1·395	2·79	4·185	5·58	6·975	8·37	9·765	11·16			
	Sq. section allowed ..	12	12	12	12	12	12	12	12	12			
	Weight a ft.	40	40	40	40	40	40	40	40	40			
	Length in ft.	30	30	30	30	30	30	30	30	30			
	Weight in lbs.	1200	1200	1200	1200	1200	1200	1200	1200	1200	10,800	10,800	21,600
Lower chords	Tension	120·6	117·25	110·55	100·5	87·10	70·35	50·25	26·8	3·35			
	Sq. section by calculation	24·12	23·450	22·11	20·1	17·42	14·07	10·05	5·36	0·670			
	Sq. section allowed ..	24·12	23·45	22·11	20·1	18	18	18	18	18			
	Weight a ft.	81·04	78·79	74·29	67·54	60·48	60·48	60·48	60·48	60·48			
	Length in ft.	18	18	18	18	18	18	18	18	18			
	Weight in lbs.	1458·7	1418·2	1337·2	1215·7	1088·64	1088·64	1088·64	1088·64	1088·64	10,873	9,414·3	20,287·8
Upper chords	Compression	120·6	120·6	117·25	110·55	100·5	87·10	70·35	50·25	26·8			
	Sq. section by calculation	30·15	30·15	29·31	27·64	25·125	21·775	17·59	12·56	6·7			
	Weight a ft.	101·3	101·3	98·5	92·9	84·4	73·2	59·1	42·2	22·5			
	Length in ft.	18	18	18	18	18	18	18	18	18			
	Weight in lbs.	1823·4	1823·4	1773	1672·2	1519·2	1317·6	1063·8	759·6	405·0	12,157·2	10,333·8	22,491·0
											Total		78,741·3

ADDITIONAL WEIGHT.

	lbs.
Weight of 61 floor-beams, iron, 12 in. deep × 20 ft. 6 in. long, at 820 lbs. each	41,820
,, 2 longitudinal girders, 6 in. deep under track, 2 × 306 × 25 lbs.	15,300
,, 36 pairs of 9 in. overhead cross-channels, 20 ft. 6 in. long, at 328 lbs. each ..	23,616
,, corner braces, 36 × 132	4,752
,, rods and rings of vertical cross-bracing	6,244
,, lattice and connecting-bars of 16 sets of truss posts, at 1056 lbs.	16,008
Weight of 2 sets of overhead horizontal tie-rods and rings, 1½ in. diam., 568 lbs. × 16 ..	10,224
,, iron rails, 76 lbs. a yd.	15,300
,, wooden stringers and bridging	51,408
Total	187,672

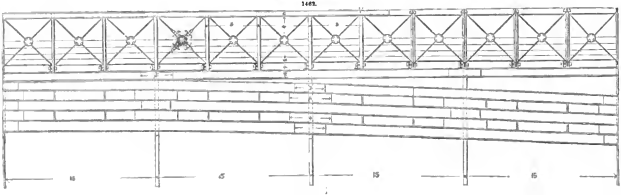
One-half this amount for a single truss	93,836
Weight of extra items, comprising all the splicing-plates of the channel-bars, the rail splices, spikes, clamps, stirrups, rivet-heads, bolt-heads and nuts, short bolts, washers, and so on ..	17,142·7
Total aggregate weight of one single line of truss	189·720 lbs.
Total aggregate weight of the whole bridge	189·72 tons.

1460.

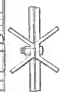


1461.

1462.



1463.



above. The following Table shows how this is done: the sixth line gives the number of sq. in. of section required in the top plate in each panel.

TABLE OF SECTIONAL AREA OF TOP PLATE IN EACH PANEL.

Number of Panel.	0	1	2	3	4	5	6	7	8
Total section of one top plate	114·75	114·75	114·75	114·75	114·75	114·75	114·75	114·75	114·75
Section required for upper chord of structure	30·15	30·15	29·31	27·64	25·12	21·775	17·59	12·56	6·7
Aggregate section ..	144·90	144·90	144·06	142·39	139·87	136·525	132·34	127·31	121·45
Deduct assumed section of channels ..	56·00	56·00	56·00	56·00	56·00	56·00	56·00	56·00	56·00
Leaves for section of top plate	88·90	88·90	88·06	86·39	83·87	80·525	76·34	71·31	65·45
Dimensions of top plate	in. in. 42 × 2·11	in. in. 42 × 2·11	in. in. 42 × 2·09	in. in. 42 × 2·05	in. in. 42 × 1·99	in. in. 42 × 1·92	in. in. 42 × 1·81	in. in. 42 × 1·70	in. in. 42 × 1·55

Recapitulation of whole Weight.

	lbs.
Tie-rods, counter-rods, posts, upper and lower chords on one side	78,741·3
Additional weight on one side	93,836·0
Extra items	17,142·7
Weight of top plate on one side, 114·75 × 3·36 = 385·5 per foot, or 385 × 5 × 3·06 = ...	117,963·0
One cable, 312 ft. × 19 × 5·09 lbs.	30,173·0
Suspenders, &c., 36 × 306, or, for one side, 18 × 306	5,508·0

One-half weight of whole structure .. .. 343,364 lbs.
Total weight of the entire structure .. .. 343·36 tons.

$$\text{Weight per foot} = \frac{343 \cdot 36}{306} = 1 \cdot 122 \text{ ton.}$$

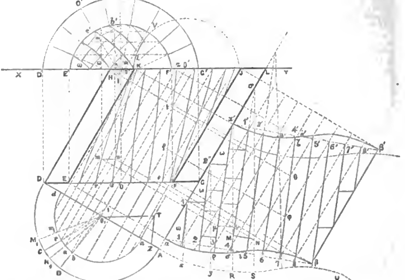
For further particulars respecting this system, the reader is referred to Roebling's large work, published by D. Van Nostrand, N.Y.

Oblique Bridges are bridges in which the axis of the arch meets the supports in an oblique direction. Railways have much necessity for this kind of bridges, because the survey frequently makes it necessary to carry the track over a road or a canal, which it intersects at an angle more or less acute. From obvious economical considerations, only the leading arches and courses of the springers are constructed of hewn stone; the body of the arch is formed of materials of a weaker description, often of bricks. These considerations have led engineers to the conception of a plan appropriate to this kind of construction. Three principal systems are at present in use in the construction of *oblique bridges*: the helicoidal arrangement, which was originated in England; the orthogonal arrangement, invented in France; and that of upright arches *en retraite*, a very ancient system lately brought into use. In each of the two first systems, the arch is semicircular, and it is the mode of its subdivision into voussoirs which distinguishes it from ordinary semicircular arches.

The Helicoidal Arrangement.—This is so named from the fact that the edges of the inward arch are spirals, and the bed-joints, as well as the upright joints, are helicoidal surfaces of square-threaded screws. This arrangement is determined in the following manner:—Let E K and F J, Fig. 1464, be the spring lines of the intrados, D H and G L those of the extrados; H L and D G the horizontal draughts of the principal planes; let E′ V F′ and K V J be the vertical projections of the intersections of these principal planes with the intrados; let D′ C′ B′ G′ be the projection of the intersection of the extrados on the plane D G; finally, let $a\,b\,c\,d$ and A B C D be the upright sections of the intrados and extrados, developed upon the plane of the spring, which is here the horizontal plane. We will suppose these upright sections to be circles, and commence by constructing at $a\,\beta\,\beta'\,a'$ the development of the intrados: we draw the chords $a\,\beta$ and $a'\,\beta'$, dividing them into the same number of equal parts, at the points 1, 2, 3, and so on; 1′, 2′, 3′, and so on. We join any one point of division of $a'\,\beta'$ with a point of division of $a\,\beta$, so chosen that the line of junction differs as little as possible from a perpendicular common to the two chords $a\,\beta$ and $a'\,\beta'$. We see here, for example, that to fulfil these conditions it is necessary to join the point 4′ to the point 7; in the same way the point 3′ to the point 6, the point 2′ to the point 5, and so on; the point 5′ to the point 8, and so on with the rest. We shall thus obtain a series of parallel and equidistant right lines. The number of the divisions of $a\,\beta$ or $a'\,\beta'$ should be regulated in such a manner that the distance of two consecutive parallels should be equal to the thickness of the materials which are intended to be used for the body of the arch, or should only slightly exceed that thickness. If we imagine the figure $a\,\beta\,\beta'\,a'$ to be applied upon the cylinder of the intrados, the parallels in question will become spiral parallels. These are the spirals which are taken as a guide for the edges of the inward arch. We obtain the projections of these spirals in the following manner:—If from the points of division of $a\,\beta$ and $a'\,\beta'$, which occupy the same level, we draw right lines, they will be parallel to the axis O O′ of the arch, and will be nothing more or less than the generatrices of the intrados. To obtain the projections of these generating lines, we must divide the half-circumference $a\,b\,c\,d$ into as many equal parts as $a\,\beta$; and from the points of division

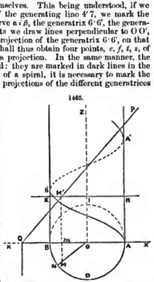
draw parallels to O O′; these are the horizontal projections of the generating lines. From the points where these projections meet the right line E F, we draw perpendiculars to the base line X Y; the points where these perpendiculars meet the semi-ellipse E′ V F′ will belong to the vertical projections of the corresponding generatrices; and, by drawing from these last points lines

1464.



parallel to X Y, we shall have the vertical projections themselves. This being understood, if we wish to obtain, for example, the horizontal projection of the generating line 4′ 7, we mark the points ϵ, ϕ, θ, ζ, where it meets successively the leading curve $a\,i\,\beta$, the generatrix 6′ 6′, the generatrix 5′ 5′, and the leading curve $a'\,i'\,\beta'$; from these points we draw lines perpendicular to O O′, ending respectively on the right line E F, the horizontal projection of the generatrix 6′ 6′, on that of the generatrix 5′ 5′, finally on the right line K J; we shall thus obtain four points, e, f, t, z, of the required projection, and it will be easy to trace this projection. In the same manner, the horizontal projection of the other spirals will be obtained: they are marked in dark lines in the quadrilateral E F J K. To obtain the vertical projection of a spiral, it is necessary to mark the points where its horizontal projection meets the horizontal projections of the different generatrices of the cylinder, and from these points to draw lines perpendicular to the base line, until they meet the vertical projections of the same generatrices; we thus obtain the curves $c'\,k$, $b'\,l$, and so on.

1465.



Spiral surfaces with a square-threaded twist are taken for the bed-joints; that is, each of these joints is governed by a right line subject to remain parallel to the plane of the upright section of the cylinder, and to rest constantly upon the axis O O′ of this cylinder, and upon the spiral which forms the edge of the inner arch corresponding to the joint under consideration. Before going further, it is necessary to determine the intersection of these spiral joints with the leading planes. The intersection of a spiral surface with a plane may be constructed by the ordinary methods of descriptive geometry. Let us suppose that the vertical line O I, Fig. 1465, is the axis of the surface; and that the directing spiral has for its horizontal projection the circumference O A, and for its vertical projection the sinusoid A B′ A′ . . . . .; and let P Q be the vertical tracing of the intersecting plane, supposed to be perpendicular to the vertical plane of projection. Draw any auxiliary horizontal plane K H; this auxiliary plane will intersect the helicoidal surface according to a horizontal line which is projected vertically upon K H, and horizontally according to a radius O N, which will be determined by the condition that the arc A D N shall be to the entire circumference in the

ratio of A H to the space A A′. The same auxiliary plane will intersect the plane P Q, according to a line perpendicular to the vertical plane, which is projected vertically according to the point M′, and horizontally, according to a line m M, perpendicular to the base line. The point M, M′, belonging at the same time to the generatrix I H, O N_2, and to the intersection of the auxiliary and the intersecting planes, is a point of the intersection of the plane P Q with the helicoidal surface. We can obtain in the same manner as many points of this intersection as may be desired. For facility of working, it will be convenient to divide the circumference A B and the space A A′ into the same number of equal parts starting from the point A, the points of division of the same level will give the radius analogous to O N, and the horizontal plane analogous to K H, which will determine one point of the desired line. Having the projections of the required intersection, we can obtain it in its true dimensions by describing the plane P Q around its vertical tracing.

To solve the same problem, we can also employ calculation. If we take for the axis of z the axis O I of the surface, for axis of x the direction of the radius O A, and for axis of y a perpendicular radius, designating by h the space A A′ of the directing spiral, we shall have for equation of the helicoidal surface,

$$z = \frac{h}{2\pi} \text{ arc tan. } \frac{y}{x}. \qquad [1]$$

If a designates the angle of P Q with the axis of x, and b the distance $o\,c$, we shall have for equation of the intersecting plane,

$$z = x \text{ tan. } a + b. \qquad [2]$$

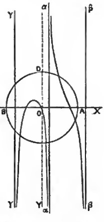
Eliminating z from these two equations, we obtain the equation of the projection of the desired intersection upon the plane of $x\,y$; that is, $\frac{h}{2\pi}$ arc tan. $\frac{x}{y} = x$ tan. $a + b$, whence

$$y = x \text{ tan. } \frac{2\pi}{h}(x \text{ tan. } a + b), \qquad [3]$$

which curve we can construct by points. The intersection of the dividing plane with the vertical cylinder, which has this curve for its base, will be the intersection of the same dividing plane with the helicoid surface.

Whichever of the two methods we employ, we shall find that the curve which has for its equation the relation [3], has a form analogous to that indicated in Fig. 1466. It is composed of two branches which have a common asymptote $\alpha\,\alpha$, and two other asymptotes, belonging one to each, $\beta\,\beta$, $\gamma\,\gamma$, all three parallel to the axis of y. Other branches and other asymptotes may be obtained by paying attention to the undefined part of the helicoidal surface, which is extended outside the cylinder, whose base is the circle A D B; but this consideration is of no value in the question with which we are occupied. If we imagine a vertical cylinder, having for its base the two-branched curve of Fig. 1466, we have seen that its intersection by the cutting plane P Q, Fig. 1465, will be at the same time the intersection of this plane with the helicoidal surface. This intersection will evidently have a form analogous to the curve in 1466.

1466.



For each helicoidal joint it would be necessary to construct an analogous curve, if it were desired to have exactly its intersection with the leading plane. But when the upright section of the arch has a great radius, as is often the case, the intersections of the joints with the leading plane have only a slight curvature, and may, without any appreciable error, be considered as right lines; we can then, in the construction of these lines, profit by a remarkable property of these curves. If from points, such as b' and c', Fig. 1464, where the intersections of the helicoidal joints with the leading plane meet the curve of the intrados E′, c', b', F′, we draw tangents to these intersections, all these tangents will come together at one point I′, situated upon the vertical line of the centre O″. Let us now consider the equation [3]; taking the differentials of the two terms, we obtain

$$y' = \text{tan. } \frac{2\pi}{h}(x \text{ tan. } a + b) + \frac{x\,\delta\,\frac{2\pi}{h} \text{ tan. } a}{\cos.^2 \frac{2\pi}{h}(x \text{ tan. } a + b)}.$$

Now the ordinate Y of the point, where the tangent of this curve meets the axis of y, has for its equivalent $y - y'x$; substituting for y and y' their equivalents, and reducing, we obtain

$$Y = \frac{2\pi \text{ tan. } a}{h} \; \frac{x^2}{\cos.^2 \frac{2\pi}{h}(x \text{ tan. } a + b)}.$$

But the equation of the curve gives tan. $\frac{2\pi}{h}(x \text{ tan. } a + b) = \frac{y}{x}$, whence we get

$$\cos.^2 \frac{2\pi}{h}(x \text{ tan. } a + b) = \frac{x^2}{x^2 + y^2}.$$

Substituting for Y, it follows that $Y = \frac{2\pi \text{ tan. } a}{h}(x^2 + y^2)$.

If we consider in particular the point of the curve which is on the circumference O A, Fig. 1460, the radius of which we represent by r, we may write

$$Y = \frac{2\pi \tan. \alpha}{h} r^2, \qquad [4]$$

which expression is independent of b; that is to say, the distance Y would remain the same if we transposed the intersecting plane P Q in a direction parallel to itself, or, what amounts to the same, if we caused the helicoidal surface to revolve in a direction parallel to its axis. Let us observe now, that all the right lines, which on being described round the cylinder of the intrados, have become the edges of the inner arch, being parallel right lines; these edges of the inner arch are equal spirals. The surfaces of the joints which have these spirals as directing lines are then equal themselves; and they can be made to coincide by causing them to revolve sufficiently in a direction parallel to the axis of the intrados. It follows from this that in place of cutting all the surfaces of the joints by the leading plane, we should obtain the same intersections by cutting only one of them by planes parallel to the leading plane situated at convenient distances from this leading plane. The projections of the curves of intersection upon the plane of the upright section will then also be the same, that is, that to obtain them it is sufficient properly to vary b in the equation [3]. But the distance Y is independent of b; hence, if from the points where the different curves which are projections of the intersections of the surfaces of the joints by the leading plane, meet the circumference $a\,b\,d$, Fig. 1464, we draw tangents to those curves, they will come together at a point I, situated on the axis O O' at a distance from the centre indicated by the expression of Y. But we know that the projection of the tangent of a curve is itself a tangent of the projection of this curve. If then the lines B b, C c, and so on, Fig. 1464, are the projections of the lines B' b', C' c', and so on, upon the plane of the upright section, the tangents at b, c, and so on, are the projections of the tangents at b', c', and so on. Now the tangents at b, c, and so on, come together at one point I, then the projecting planes of which these tangents are the tracings, and which are all parallel to the axis O O', intersect in the direction of a line parallel to this axis passing through the point I. This parallel line meets the leading plane at a point of the vertical of the point O, which is projected at I' to a distance from O'' equal to O_1 I; finally, then, the tangents of the points b', c', and so on, all meet together at the point I'.

The distance O'' I', or, in absolute valuo, Y, is easily constructed. From the centre O of the upright section we draw a line parallel to the tracing E F of the leading plane, until it meets at T with the prolongation a F of the line of the spring; and from the point T we draw T Z parallel to the right lines 4'·7, or 3'·6, and so on, which are the development of the edges of the inner arch; a Z will be the desired distance. We have already called α the angle G D A which the leading plane makes with the axis of the intrados; let us now call i the angle a T Z, equal to the angle $\alpha\,\alpha'$ 3 which the developed spiral makes with a line parallel to the axis; there results from this, $\tan. i = \frac{2\pi r}{h}$. Now the triangle O_1 T a gives T a = O_1 a tan. α = r tan. α, and the triangle T a z gives a Z = T a tan. i = r tan. α tan. i = r tan. $\alpha \frac{2\pi r}{h}$, a quantity which is equal to Y in absolute value.

The application of this property to the purpose we are considering is easily made; join the points b,' c', and so on, to the point 1'; the prolongations B' b', C' c', and so on, of the lines of junction will be the tangents at b,' c', and so on, to the intersections of the surfaces of the joints by the leading planes, and may be taken for these intersections themselves under ordinary circumstances where these curves have only an inappreciable curvature.

To determine the upright joints, draw right lines such as $\mu\,\nu$, Fig. 1464, perpendicular to the right lines $\rho\,\alpha'$, $\sigma\,\gamma$, and so on, which are the development of the edges of the inner arch. Only a few of these perpendiculars are marked on the sketch. When the figure $\alpha\,\beta\,\beta'\,\alpha'$ is applied to the cylinder of the intrados, the perpendicular in question become arcs of spirals, such as that which is projected at $m\,n$, normal to the edges of the inner arch. Helicoidal surfaces with a square threaded twist having these spirals for directrices are taken for the upright joints. The arch is thus divided into voussoirs by surfaces normal to the inner arch and perpendicular to one another, which is the essential condition of the arrangement of an arch. To obtain an intermediate point of the spiral projected at $m\,n$, we take an intermediate point upon the right line $\mu\,\nu$, for example, that which is found upon the generatrix 3·3'; drawing from this point a line perpendicular to O O' until we meet with the horizontal projection of the generatrix corresponding to 3·3, we shall have the horizontal projection of the desired point. To get the vertical projections corresponding to m and n, it will be sufficient to draw from these points, perpendiculars to the base line until we meet at m' and n' with the lines $c'\,k$ and $b'\,l$, vertical projections of the generatrices, of which $r\,m$ and $s\,n$ are the horizontal projections. As to the intermediate point between m and n, we shall draw from this point a line perpendicular to A D, and one perpendicular to X Y; taking that portion of the former which is comprised between A D and the circle $a\,b\,c\,d$, we shall carry it on to the second starting from X Y; we shall thus have an intermediate point upon the projection $m'\,n'$. We may proceed in the same manner for the other upright joints. We have at $\mu\,\nu\,\sigma\,\rho$ the development of the panel of the inner arch corresponding to that portion of the intrados comprised between the joint $m\,n$ and the leading plane. The surfaces of the joints cut the extrados in the direction of spirals having respectively the same space; and this consideration affords the means of obtaining the development of the panel of the extrados which corresponds to the panel $\mu\,\nu\,\sigma\,\rho$ of the intrados. In fact, the two bed-joints and the upright joint which form the limits of the voussoir corresponding to $m\,n\,s\,r$, are cut according to two right lines starting from the points m, m', and n, n', which, being the generatrices of the two bed-joints, are parallel to the upright section of the intrados and meet the axis O O'. These horizontal projections will then be directed

according to lines perpendicular to O O′ drawn from the points m and n; and if we develop the extrados, the points where the surface is met by the said generatrices will fall at M and N situated upon the prolongation of the right lines $m\,\mu$ and $n\,\nu$. On the other hand, if A U is the development of the leading arc of the extrados, supposed to be obtained in the same manner as for the intrados, the point projected at C′ will fall at R, and the point projected at B′ will fall at S. The spirals of the extrados which pass through these two points having the same space as those of the intrados which pass through the points ρ and σ, will give, on development, right lines which will meet together at the same points of the line of a L, starting from which we effected the two developments; that is to say, the spiral corresponding to the point R will give the right line R a', which converges with $\rho\,a$ to the same point a'; and the spiral corresponding to the point S will give the right line S σ', which converges with $\sigma\,\sigma'$ to the same point σ' of the line a L. These right lines R a' and S σ' will determine the points M and N; and we shall have at M N S R the development of the panel of the extrados corresponding to the panel $\mu\,\nu\,\sigma\,\rho$ of the intrados.

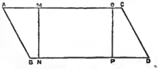
Before proceeding to cut the voussoir, it is still necessary to effect its projection on the plane of the right section. For this, draw from the points m and n perpendiculars to A D until they meet the circumference $a\,b\,c\,d$ at m_1 and n_1; then from the centre O, take the radii $m_1\,M_1$, and $n_1\,N_1$; these will be the projections of the generatrices of joints which pass along the points m', m', and n, n'. We have already the right lines B b and C c which concur at the point I, the projection of the voussoir under consideration will be comprised between the right lines B b and $M_1\,n_1$. To apply the draught upon stone, prepare a prism having for its base the curvilinear quadrilateral B $b\,m_1$ M_1 and for its height the distance of the points r and s computed parallel to O O′. After having marked upon the two bases the points b, c, m_1, n_1, B, C, M_1, N_1, join the corresponding points by right line, which will be the generatrices of the cylinders of the intrados and the extrados. Upon the concave cylindrical surface apply the flexible panel $\mu\,\nu\,\sigma\,\rho$ in such a way that the point ν falls at n_1, upon one of the bases, the point ρ at c upon the other base, the point σ upon the generatrix starting from b, and the point μ upon the generatrix starting from m_1. Apply upon the convex cylindrical surface the flexible panel M N S R, in such a way that the point N falls at N, upon one of the bases, the point R at C upon the other base, the point S upon the generatrix starting from B, and the point M upon the generatrix starting from M_1. By the help of these two panels trace spirals answering to the right lines $\mu\,\rho$, $\nu\,\sigma$, $\mu\,\nu$, M R, N S, M N, and the elliptical arcs corresponding to the curves $\rho\,\sigma$ and R S. These two last arcs will determine the plane of the heading face, and allow the face to be cut. As for the spiral joints, they will be cut by using a rule passing along points of reference marked out previously upon the right lines $\mu\,\rho$ and M R, upon the right lines $\mu\,\rho$ and N S, and upon the right lines $\mu\,\nu$ and M N. These points of reference are obtained easily by dividing into the same number of equal parts the right corresponding lines upon which they have to be marked. In the same way all the voussoirs belonging to the leading arcs may be cut.

Supposing the arch to be entirely constructed of ashlar work, all the longitudinal voussoirs might be cut in the same manner. They could also be obtained by a method exactly similar to that used in shaping the stones for the helix of a corkscrew staircase. But more generally the body of the arch is constructed, as has been said, of materials of small dimension, for example, of bricks. The stones which compose this construction are then identical one with another, and to place them properly, spread upon the framework, which is to bear the arch for a time, a layer of plaster forming a cylinder equal to the intrados, upon this layer trace the spirals which form the edges of the inner arch; the distance from one to another is that of the thickness of the stones which are to be used; it only remains to place these latter in the intervals between the spirals, so that the face which is to form the inner arch coincides with the layer of plaster, and they are then united by cement.

Independently of the voussoirs belonging to the head arches, the upper course of the imposts, and the triangular voussoirs marked by the letter ω in Fig. 1459, named coussinets, are constructed of stone. These coussinets must be firmly fixed in order to resist the thrust of the layers which have a tendency to slip along the bed-joints, considerably inclined towards the springers. For this reason the coussinets are shaped so as to fit in with the stones of the upper course of the imposts. These coussinets have a concave-cylindrical face on the intrados, a convex-cylindrical face on the extrados, a spiral face making part of a bed-joint, and a spiral face forming an upright joint. They are shaped like the heading voussoirs, by means of panels of development of the faces of the intrados and extrados; the figures a 1″ 1 and A 1″ x, Fig. 1464, represent these two developments for the first coussinet on the left.

The defect of the helicoidal arrangement lies in the tendency of certain courses to slip outwards: thus the course projected at $b'\,c'\,k\,l$, Fig. 1464, has a tendency to slip towards the back of the arch. To avoid this defect, the helicoidal arrangement may be limited to that portion of the arch comprised between the leading plane and a neighbouring upright section. If, for example, A B and C B, Fig. 1467, represent the horizontal tracing of the leading planes, and M N and O P those of two neighbouring upright sections, the helicoidal arrangement may be employed only for the portions A B N M and C D P O of the arch, and the portion M N P O be arranged as in an ordinary cylindrical arch. The courses which have a tendency to slip outwards, at C and at B, are thus suppressed, or at least reduced to the leading voussoirs. More especially in case the arch is intended to be of great length will it be useful to adopt this arrangement.

1467.

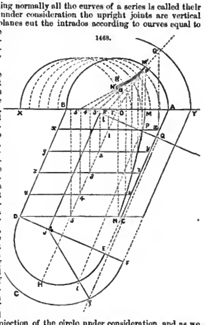


The helicoidal arrangement has also been charged with a tendency in the courses to become twisted when the framework is taken away and before the mortar has acquired a proper consistency. To remedy this, it has been proposed to replace the upright spiral joints by plane joints parallel

to the leading planes. But, on this supposition, it would be preferable to adopt the orthogonal arrangement.

The Orthogonal Arrangement.—A line meeting normally all the curves of a series is called their orthogonal trajectory. In the arrangement under consideration the upright joints are vertical planes parallel to the leading planes; these planes cut the intrados according to curves equal to the leading arcs, ellipses for instance; the edges of the suffits are the orthogonal trajectories of these equal curves, and the arrangement ought to be called the arrangement by orthogonal trajectories.

1468.



The projections of these trajectories are constructed in the following manner. Let A C and B D, Fig. 1468, be the spring lines of the arch; we shall take the plane of the spring for the horizontal plane of projection, and the leading plane A B for the vertical plane. To make it more clear, we shall suppose that, as is most frequently the case, the leading curves are circles. Let $x\,x$, $y\,y$, $z\,z$, $u\,u$, be the tracings of planes parallel to the leading planes, and which determine the upright joints; let 0, 1′, 2′, 3′, 4′, 5′, be the centres of circles according to which the intersections of these planes with the intrados are projected. It will be noticed at the outset that each of the required trajectories is projected upon the vertical plane according to a curve which is itself an orthogonal trajectory of the circles whose centres are 0, 1′, 2′, 3′, 4′, 5′. For if we consider by itself one of the required trajectories, at the point where it meets one of the circles $x\,x$, $y\,y$, and so on, its tangent is perpendicular to the tangent of this circle, which is parallel to the vertical plane. Now, when a right angle has one of its sides parallel to one of the planes of projection, we know that it is projected upon this plane at a right angle; the tangent of the trajectory in question then is projected vertically according to the normal of the projection of the circle under consideration, and as we can say the same of all the analogous circles, it results that the projection of the trajectory meets all these circles normally, and that it is in consequence their orthogonal trajectory.

This trajectory of the circles 0, 1′, 2′, and so on, may be determined exactly by calculation. Any one of these circles has for its equation

$$(x - a)^2 + y^2 = R^2, \qquad [5]$$

R designating the radius and a the abscissa of the circle, computed on X Y, starting from any part; for example, from the point A. It is demonstrable, by the differential calculus, that to obtain the orthogonal trajectory of a series of curves, we must state the equation

$$1 + y'\frac{dy}{dx} = 0, \qquad [6]$$

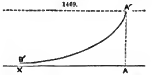
in which y' represents the angular coefficient of the tangent to one of the proposed curves, and must eliminate from this proportion and the general equation of these curves, the variable parameter which belongs to each curve. From the equation [5] we obtain $y' = -\frac{x-d}{y}$, consequently we should have $1 - \frac{(x-d)}{y}\frac{dy}{dx} = 0$; eliminating d from this proportion and the equation [5], and then integrating, we obtain for the equation of the required trajectory

$$x = \log.'\frac{R - \sqrt{R^2 - y^2}}{y} + \frac{\sqrt{R^2 - y^2}}{R} + \text{const.} \qquad [7]$$

We see that all the orthogonal trajectories of the circles 0, 1′, 2′, 3′, and so on, are equal curves, and that having obtained one of them, we shall get all the others by causing the first to revolve parallel to the axis X Y. If, for example, we suppose the arbitrary constant = O, we shall find for x and y the corresponding values stated in the following Table:—

Values of $\frac{y}{R}$		Values of $\frac{x}{R}$	
1	0·4	0·000	−0·649
0·9	0·3	−0·031	−0·918
0·8	0·2	−0·092	−1·310
0·7	0·1	−0·183	−1·993
0·6	0·0	−0·298	− ∞
0·5		−0·460	

1469.



These values correspond with a curve of the form indicated in Fig. 1469. If the sections parallel

to the leading planes were ellipses having for semi-axes a and b, we should likewise find for the equation of the orthogonal trajectory of their projections upon the vertical plane

$$x = \frac{b^2}{a}\left[\log.'\frac{b - \sqrt{b^2 - y^2}}{y} + \frac{\sqrt{b^2 - y^2}}{b}\right] + \text{const.}$$

Instead of having recourse to calculation, we may construct the curve approximately by the property which serves for its definition. For example, let M′, Fig. 1468, be the first point from which we wish to draw an orthogonal trajectory of the circles 0, 1′, 2′, 3′, and so on. If from the point M′ we draw a right line in the direction of the point 0, until it meets the circle 1′; from the point of meeting, a right line in the direction of 1′, until it meets the circle 2′; from the new point of meeting, a right line in the direction of 2′, until it meets the circle 3′; and so on; we shall obtain a broken line M′ d, which will differ less and less from the desired curve, in proportion as the sections $x\,x$, $y\,y$, $z\,z$, and so on, are nearer one to another. But it will be a little lower in position than this curve, because its successive sides are normal only to the circle which passes round their upper extremities. If on the contrary we join M′ to the point 1′, arresting the line of junction at the circle 1′, and from the point of meeting draw a right line in the direction of the point 2′, until it meets the circle 2′, and so on, we shall have a second broken line M′ B, which will also differ very little from the desired trajectory, but which will be a little higher in position, because its sides are normal only to the curve which passes round their lower extremities. If, then, we form a broken line M′ N′, by joining the middle points of the arcs of the circles intercepted by the two lines M′β and M′ a, the line thus traced will differ still less than the two preceding from the curve we wish to obtain.

The projection M′ N′ of the trajectory, which is to serve as the edge of the inner arch, being obtained by one of the above methods, we can easily deduce therefrom its horizontal projection; to do this, from the points at which M′ N′ meets the circles 0, 1′, 2′, 3′, 4′, 5′, we let fall perpendiculars to the base line, terminated at the right lines A B, $x\,x$, $y\,y$, $z\,z$, $u\,u$, C D, horizontal projections of these circles; and joining by a continuous curve the points thus determined, we shall have the projection M N of the trajectory upon the horizontal plane.

We take for the bed-joint corresponding with each edge of the inner arch the left surface formed by the normals to the intrados drawn from the different parts of this line. To obtain the normal to the intrados at any point of the trajectory M N, M′ N′,—at the point P, P′, for example,—it will be observed that this normal is perpendicular to the tangent of the circle $x\,x$; and as the latter is perpendicular to the vertical plane, the normal, for the reason already given, will be projected vertically according to a perpendicular to the tangent at P′ of the circle 1′; that is, according to the normal P′ Q′ to this circle. Besides, the normal to the intrados being included in the plane of the upright section, it will be projected horizontally upon the horizontal tracing of this section, that is to say, perpendicularly to the axis of the arch, or according to P Q perpendicular to A C. We proceed in the same way for all the other normals; the bed-joint is then determined by its rectilinear generatrices.

It is necessary to determine its intersection with the extrados. Let D H E be the upright section of the intrados, and F G that of the extrados, brought down upon the horizontal plane. To get the point of junction of the normal P Q, P′ Q′, with the extrados, we first draw from the point P a parallel to the axis of the arch, until it meets at p with the section E H D; then, after having determined the horizontal tracing I of the normal, we project it at i upon D E; next joining $i\,p$, we shall have the projection of the normal upon the plane of the right section; prolonging this until it meets at q the curve of the extrados F G; draw from the point q a perpendicular to D E, which will determine the point Q; then a perpendicular to X Y, which will determine the point Q′. Proceeding in the same manner for the other normals, we shall obtain the projections of the intersections of the bed-joint in relation to the surface of the extrados; and the same for the other bed-joints.

Develop, by the ordinary methods, the surface of the intrados and the surface of the extrados with the curves there traced; and we shall have the developments of the panels of the inner arch, and the corresponding panels of the extrados.

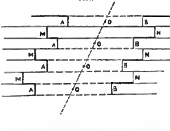
Supposing the arch entirely constructed of ashlar work, each voussoir would be shaped by a method analogous to that explained in treating of the helicoidal arrangement. The four normals which form the angles of the voussoir having been projected upon the plane of the right section, we have the projection of the voussoir upon this plane. Upon this projection is constructed an upright prism, having for height the distance of the two plane joints; for example, the distance of the right lines $x\,x$ and $y\,y$. Upon the concave face of the cylinder we apply the panel of the inner arch, and upon the convex face the corresponding panel of the extrados: the two left joints will be shaped by aid of a rule extended along guiding points marked out beforehand upon each edge of the inner arch, and upon the curved edge which corresponds to the extrados. But more generally, the body of the arch being constructed of rough stones, or of bricks, a layer of plaster is prepared coinciding with the intrados; upon this layer is traced, by the aid of the development of the intrados, the orthogonal trajectories, between which it only remains to arrange the stones intended to form the arch. There will here be a little difficulty additional to that met with in the helicoidal arrangement; the trajectories, although equal one to the other, are not equidistant, and it is necessary in consequence to vary the thickness of the stone employed, according to the distance of the two curves between which it has to be placed. As to the heading voussoirs, they form a sort of arch independent of the principal arch; it results, in fact, from the defective parallelism of the edges of the inner arch that the bed-joints could not be prolonged as far as the leading planes without causing in the size of the heading voussoirs inequalities which would be displeasing to the eye; these voussoirs are then shaped independently, making the bed-joints normal to the leading planes. The shaping of these voussoirs then presents no difficulty; the

plane faces being executed, the cylindrical surfaces are afterwards shaped by means of a rule placed along guiding points chosen beforehand.

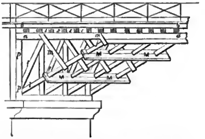
An important simplification has been proposed in the construction of the arch under consideration, which consists in replacing the left bed-joints by the cylindrical surfaces projected by the trajectories upon the leading planes, surfaces which in fact differ very little from the former, and which besides possess the advantage of furnishing only reactions situated in planes parallel to the leading planes, and in consequence not affording any composant perpendicular to these planes; that is to say, not giving rise to a thrust by increasing the opening. When the arch is to be of great length, we can, as shown in Fig. 1467, arrange the portion of the arch comprised between the upright sections M N and O P as an ordinary cylindrical arch, and only employ the orthogonal arrangement for the portions A B N M and C D P O. But in place of using joints running parallel to the heads, we employ vertical planes which converge, some towards the point of junction, the right lines A B and M N, and others towards that of the right lines C D and O P. The edges of the inner arch are the orthogonal trajectories of the vertical sections of the intrados thus obtained; their tracing is necessarily more complicated. This system is that which is called the convergent orthogonal arrangement. Its advantages do not appear to make up for the difficulty of its execution and the ungraceful appearance of the arch.

Parallel Arches in Echellon.—Lastly, oblique bridges are formed of a series of upright arches, equal and parallel, but placed one behind another in echellon, as is shown in Fig. 1470, in horizontal projection. These arches are ordinary upright cylindrical arches, but of unimportant length, A B, A B, and so on, whose centres O, O, and so on, are placed on the axis of the oblique arch. They are mutually united by other cylindrical arches M N, M N, whose voussoirs are embayed to a greater or less extent in the thickness of the principal arches. The system is inelegant in appearance.

1470.



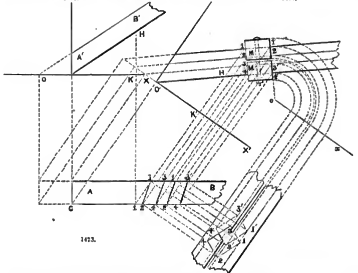
1471.



Oblique Bridges of Timber.—Oblique bridges are also constructed of wood, but they are all formed on the principle of the upright arches in echellon; that is, they are composed of a certain number of equal and parallel girders placed in echellon to one another, in such a manner that their homologous points are situated upon right lines parallel to the axis of the bridge, or the direction of the piers. Fig. 1471 represents the vertical projection of a semi-arch of such an arrangement, which is frequently used for the erection of a more permanent structure. Each girder is composed of a horizontal beam *a a*, supported by an upright post *p p*, by a principal rafter *j j*, and a strut *f*. These different parts are united by hanging-braces *m*, *m*. Upon these girders are placed the joists *s s s s*, which support the roadway *b b* of the bridge. In the example given in Fig. 1471, the number of girders is four. The principal difficulty of this mode of construction consists in the method to be adopted to bind together the different girders, in order to form the whole into a perfectly solid system. The method most in use is that of uniting all the girders by horizontal braces M M, which are then parallel to the direction of the piers. But as the rafters pass through the braces in an oblique direction, it is necessary to determine by a draught the apertures to be excavated in these braces. Let A B and A′ B′ be, Fig. 1472 and 1473, the projections of one of these rafters, in relation to a horizontal plane passing through its lowest point O. It is necessary to first fix the transverse dimensions of the braces, by projecting the rafter upon a vertical plane perpendicular to the direction of the piers. Let C O′ be this direction, and let O′ X perpendicular to C O′ be the near ground line. Upon the horizontal projection of the edge which starts from the point C, take any point I, which projects at K upon O X and at K′ upon O′ X′. Prolong the perpendiculars, and take upon the second a length K′ H′ equal to the distance K H, and join O′ H′, which will be the near vertical projection of the edge which touches the point C. The projections of the other edges will be easily obtained from this, in the manner indicated on the figure. Having thus obtained, Fig. 1474, the vertical projections of the rafters upon a vertical plane perpendicular to the direction of the braces, we can determine the upright sections M M of these braces. Mark the points 1, 2, 3, 4, and 1′, 2′, 3′, 4′, where their faces, perpendicular to the new vertical plane, meet the edges of the rafter; and project these points, Fig. 1473, upon the corresponding horizontal projections of these edges. We can thus trace the parallelograms 1 2 4 3, and 1′ 2′ 4′ 3′ according to which the rafter penetrates the lateral faces of the braces. Taking, then, in one of these faces a point *o* from which we suppose a horizontal parallel to the direction of the piers, let us imagine the braces to revolve round this horizontal, until the lateral faces of which we have just spoken have assumed a horizontal position, and in this position their different points to be projected upon the original horizontal plane of projection. Then, from the summits of the parallelograms 1, 2, 3, 4, and 1′, 2′, 3′, 4′, let fall perpendiculars upon the direction of the edges of the braces. Marking,

Fig. 1475, the intersections of these perpendiculars with the perpendiculars to ox which answer to the same figures, we shall obtain the upper and lower tracings of the apertures we wish to determine, such as will have to be drawn on the faces of the braces when executing these apertures. Only, it must be observed, that as a consequence of the rotatory movement imparted to the braces, it is the upper one which is placed to the right in Fig. 1475, and the lower one which is placed to the left. We may proceed in the same manner for the other apertures, but it will be noticed that they have their faces parallel, and this will much shorten the operation.

1472. 1474.



1473. 1475.

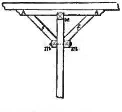
In place of uniting the rafters one to another, the hanging-braces are sometimes connected by horizontal ones. This arrangement would give rise to operations analogous to the preceding. Occasionally a direction differing from the horizontal has been given to the braces uniting the different beams.

Timber Bridge Construction.—The roadway of these temporary structures rests upon several girders, generally equidistant. The interval between two consecutive points of support is called a space.

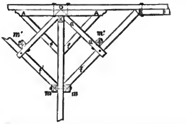
The arrangement of the girders varies considerably; we shall only deal with the systems mostly used.

Where the interval between two consecutive points of support does not exceed 5 mètres, the girders are simply horizontal beams laid upon these supports, and it is on these beams that are placed transversely the cross-beams which sustain the roadway and the pavement. If the interval is to be from 5 to 8 mètres, supplementary beams A A, Fig. 1476, projecting 2 mètres on each side and supported by struts f f, are laid upon the piles. Fig. 1476 also shows the heads m m of the horizontal braces uniting the stakes which form the pile, and the head M of the horizontal piece of timber forming the cap of the pile.

1476.



1477.



In the case of intervals of 8 to 12 mètres, a second row of struts f' f', Fig. 1477, is added, abutting upon another supplementary beam B, placed in the middle of the interval. If these secondary struts have a length exceeding twelve times their breadth, they are supported by hanging-braces a a, which are themselves united from one girder to another by horizontal braces m' m'.

For greater intervals several stages of struts or rafters united one to another by vertical hanging-braces may be employed. When the interval is of considerable length, beams bound with iron are employed. The bridge at Wittingen, over the Limmat, forming a single span of $118^{m}\cdot 90$, is cited as the most remarkable instance of this kind of construction: it is composed of several stages of armed beams, united by vertical hanging-braces, and supported by several systems of struts or rafters of different inclinations, the lowest of which is an armed beam.

In the several cases just indicated, the dimensions of a beam are calculated as if it were simply placed upon supports. The total weight for one interval of the roadway and pavement is calculated, and dividing by the number of beams, we have the weight uniformly diffused over the length of a beam. If the bridge is exposed to considerable and varying loads, these must be taken into consideration: such are, upon an ordinary load, the passage of a vehicle representing a weight of 6000 kilos.; or upon a railway, the passage of a locomotive weighing 60,000 kilos., which gives 30,000 kilos. for each beam, as one is ordinarily placed under each rail. Let a be the length of the span, p the weight a linear mètre, P the weight accidentally applied at the middle of the span, we must reconcile the two equations

$$R = \frac{1}{8}\frac{v}{I}(p + p')\,a^2 = \frac{3}{4} b\,h^2\,(p + p')\,a^2 \qquad [1]$$

and $$R = \frac{v}{I}\left(\frac{1}{8}\,p\,a^2 + \frac{1}{4}\,\mathrm{P}\,a\right) = \frac{6}{b\,h^2}\left(\frac{1}{8}\,p\,a^2 + \frac{1}{4}\,\mathrm{P}\,a\right), \qquad [2]$$

calling b the horizontal dimension of the upright section of the beam, and h its vertical dimension. We will take R equal at most to 600,000 for oak, or 800,000 for deal, say, 60 kilogrammes the square centimètre in the first case, and 80 kilogrammes in the second; find the proportion of h to b, and deduct h from these two formulæ; the greater of the two values then obtained must be adopted. We can then estimate the weight of the beam to introduce it into p, and calculate a nearer value for h.

When the same beam forms several spans, or even the total length of a bridge, it is considered as a piece of timber placed upon supports, corresponding to the piers of the abutments. We thus determine the moment of flexion corresponding to each point of support, and next the moment of flexion on any given point of the beam, the maximum of this moment, and by consequence the transverse dimensions of the beam. For the same calculations we deduce the reactions of the supports, and on the other hand the load sustained by these supports, whence we obtain the dimensions of the piles.

The dimensions of the divisions of the bridge must be calculated in the same way as for a portion of timber placed upon a certain number of supports, which are here the beams, loaded with a weight uniformly diffused, and also with a weight applied at the middle of the interval between two beams, representing the movable load caused by the passage of a vehicle. But as this calculation is a very long one, a more rapid, but less exact method is preferred. The dimensions of the portion of the bridge are calculated: 1st, as if the part of this portion comprised between two beams formed an isolated portion placed on two supports; 2nd, as if it were let into the two points of support. In the first case the maximum of the moment of flexion is given by the formula $\mu = \frac{1}{8}\,p\,a^2 + \frac{1}{4}\,\mathrm{P}\,a$; calling a the distance between two beams, p the weight uniformly spread over each portion of the bridge, and P the movable load; in the second case we should have $\mu = \frac{1}{12}\,p\,a^2 + \frac{1}{8}\,\mathrm{P}\,a$.

The mean of the values of μ given by these two formulæ is adopted. When the bridge has to support occasionally only the weight of a wagon not exceeding 4000 kilogrammes, the divisions of the bridge may be $0^{m}\cdot 50$ distant from one another; if the accidental load will be greater, they must be placed nearer together. But it is well to observe that when only a momentary load is in question, wood can be made to support a greater tension than that which we have indicated above, and that it is allowable to increase it then to 100 or 120 kilogrammes the square centimètre.

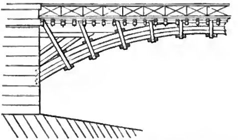
To calculate the dimensions of the struts, suppose each beam placed upon the supports which are formed by the extremities of the piles and the struts, and determine the reactions of these points of support; for struts analogous to that which abuts on the point A, Fig. 1477, we take the resultant of the reaction lengthwise to this piece of timber. It will be necessary that this resultant, divided by a transverse section of the strut, should give a quotient equal at most to 60 or 80 kilogrammes the square centimètre, according to the kind of wood employed; for struts such as those abutting on the point B, we should distribute the reaction in the direction of the strut, and in a horizontal direction; and make use of these two resultants, to determine in the same way the transverse dimensions of the strut and the underlying beam.

For bridges of great extent, there has been employed in France for fifty years, a system in which the beams and the roadway are sustained by an arch formed of a certain number of curved rafters, bound together by iron straps, and united to the roadway by hanging-braces in a direction normal to the arch. Fig. 1478 represents one division of the bridge of Ivry-sur-Seine constructed on this plan by M Emmery. The arch has a chord of $22^{m}\cdot 50$, and a versed sine of $3^{m}\cdot 48$. The roadway rests directly on the crown of the arch, and the beams are hollowed out to accord with this arch. The weight of the roadway is also transferred to the arch by means of braces. The girders are fastened one to another, not only by horizontal braces parallel to the axis of the bridge, but also by horizontal slanting beams which assist in counteracting the effects of the wind on the whole system.

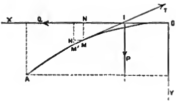
To calculate the transverse dimensions of the arch exactly, it would be necessary to consider the roadway as placed upon the hanging-braces, to determine the reactions of these supports, to

take these in a contrary sense to get the reactions of the braces upon the arch, and determine the normal component of these; we should thus have the forces which act upon the arch, independently of its weight. But we can obtain sufficiently approximative results by considering the weight of the roadway as uniformly spread over the horizontal projection of the arch. In the case we are dealing with, the formula $b\,h^2 = \frac{P}{R}\left(\frac{h}{a} + \frac{\rho\,a^2}{4}\right)$ is generally used, in which b is the transverse dimension of the arch in a horizontal direction, h its thickness vertically, P the total weight of the bridge, ρ the mean radius of the arch, a the length of the arc with a radius 1 similar to the arch under consideration, and R a coefficient which it is convenient to take as equal to 300,000.

1478.



1479.



Constructors employ a still more simple method, which gives results sufficiently near. It consists in regarding the proposed arch as the arc of a parabola, loaded with weights proportional to the horizontal projection of its elements. Let O M, Fig. 1479, be a portion of the arch computed from the vertex. Let us take for the axis of x the tangent to the vertex, for the axis of y the axis of the curve. Draw the tangent to M, and by a known property of the parabola this tangent will cut O X in the middle I of the abscissa O N of the point M. Let M' be a point infinitely near to the point M; draw the horizontal M H and the vertical M' H. The arch O M is in equilibrium, under the action of the weight P (borne by the arc and which passes through the middle I of O N), of the tension Q exercised at O in the direction O X, and the tension T which is exercised at M in the direction M I. These three forces are then proportional to the three sides of the triangle M I N, or of the triangle M M' H, which is similar to it. We have then

$$\frac{M'H}{MH} = \frac{P}{Q} \text{ or } \frac{dy}{dx} = \frac{p\,x}{Q},$$

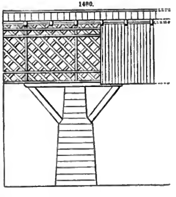
designating by P the weight a linear mètre supported by the arch. Integrating, and observing that for $x = 0$ we should have $y = 0$, we obtain for the equation of the curve $y = \frac{p}{2\,Q}x^2$. This equation must be completed by the co-ordinates of the spring; if the a is the semichord of the arch and f its versed sine, we should have $f = \frac{p}{2\,Q}a^2$, whence $Q = \frac{p\,a^2}{2f}$. We shall next have $T = \sqrt{P^2 + Q^2} = \sqrt{p^2 x^2 + \frac{p^2 a^4}{4 f^2}} = p\sqrt{x^2 + \frac{a^4}{4 f^2}}$. The maximum of T answers to $x = a$, and has for its value $T = p\,a\sqrt{1 + \frac{a^2}{4 f^2}}$. This maximum value will serve to determine the transverse dimensions of the arc.

The arch being supposed to resist only by compression, it will be necessary that the maximum tension T divided by the area of the transverse section should give a quotient at most equal to 60 kilogrammes the square centimètre for oak, or 80 kilogrammes for deal. Calling b the horizontal dimension and h the vertical dimension, we shall have $\frac{T}{b\,h} = 0{\cdot}6$. If we take the millimètre for unity, we shall obtain b, and deduce $h = \frac{T}{0{\cdot}6\,b}$.

For some years there have been constructed in America timber bridges on an entirely different system. They were invented to enable railways to pass across considerable streams of water, as we have before stated and illustrated. They are called trellis-bridges, because they have exactly the appearance of trellis-work. Fig. 1480 represents a portion of a bridge of this kind constructed at Richmond, U.S., on the system of Town. The girders, which are $5^{m}{\cdot}125$ in height, are formed of thick planks arranged trelliswise, applied flat without being let into each other, and joined by oak pegs. They are united by several courses of braces, horizontal as regards the length of the bridge, and by a certain number of vertical braces. Two equal guides are fastened together on each side of the bridge. These two girders leave between them an interval of $3^{m}{\cdot}20$. They are joined above and below by cross-beams, the intervals between which are filled by diagonal work. Other diagonals, placed vertically according to the transverse sections, complete the protection of this system against the wind. The exterior sides are covered with planks to secure the construction

against the effects of the weather, as is shown on the right side of the figure. This forms a long space of rectangular section.

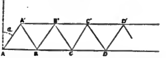
1480.



To appreciate the resistance of such a construction, we may consider each girder as a solid placed upon two supports, loaded with a weight uniformly diffused, and with a load equal to the weight of two locomotives applied in the middle of the span. But as the openings here form about two-thirds of the total volume, it is advisable to reduce to one-third the coefficient R of the resistance, that is, to 20 kilos. a square centimètre for oak, or 27 kilos. for deal. Designating by R′ the coefficient thus reduced, by p the weight of the bridge the linear mètre, by P the road applied in the middle of the span, by a the length of the span, by b the total thickness of all the traces in a horizontal direction, and by h the height of each girder, we shall have to apply the formula already used, $R' = \frac{6}{b\,h^2}\left(\frac{1}{8}\,p\,a^2 + \frac{1}{4}\,P\,a\right)$.

W. Presse, in his course of "Applied Mechanics," has endeavoured to estimate in a more precise manner the shock supported by each of the pieces composing these girders or beams of trellis-work. He considers first the simplest case to which the system would be reduced, as shown in Fig. 1481, to two courses of inclined rails, A B C D . . . . A′ B′ C′ D′ . . . . jointed with inclined ties A A′, B B′, C C′, D D′ . . . . on the one hand, and A′ B, B′ C, C′ D, on the other: and he supposes, in the first place, that the beam thus defined supports only a single weight 2 P applied in the centre. It follows at once that the beam receives from the abutment on the pier upon which it rests a vertical reaction P applied at its extremity A. Let a be the acute angle which the inclined rails make with the vertical. There must then be equilibrium between the force P applied at A and the tensions or pressures of the ties A B and A A′; it is then easily seen, by the parallelogram of forces, Fig. 1330, that the rail A A′ undergoes a pressure equal to P tan. a; and that the rail A A′ undergoes a pressure equal to $\frac{P}{\cos. a}$. If we next consider the equilibrium of the point A′, we find by the same means that the forces exercised in the direction A′ B and in the direction of the prolongation of A A′ must be equal; and that the tension of A′ B′ has for its value $2\,\frac{P}{\cos. a}\,\sin. a$, or 2 P tan. a. The equilibrium of the point B shows, on projecting the forces vertically, that the pressures of A′ B and B B′ are equal; and on projecting them horizontally, that the tension of B C is equal to P tan. a + $2\,\frac{P}{\cos. a}\,\sin. a$, that is, to 3 P tan. a. Adopting the same method with the point B′, we find that the pressure of B′ C is equal to that of B B′, and that the tension of B′ C′ has for its expression 2 P tan. a + $2\,\frac{P}{\cos. a}\,\sin. a$, that is, 4 P tan. a. Continuing thus, we find that all the ties support pressures equal to $\frac{P}{\cos. a}$; that the lower horizontal ties support successive tensions expressed by P tan. a, 3 P tan. a, 5 P tan. a, 7 P tan. a, and so on; and the upper horizontal ties, tensions expressed by 2 P tan. a, 4 P tan. a, 6 P tan. a, 8 P tan. a, and so to the middle of the span. Starting from this point, the same tensions are reproduced in inverse ratio because of the symmetry of the arrangement. If the number of the lower horizontal ties is equal, it is the middle tie which will undergo the greatest tension, and, calling $2n + 1$, the total number of these lines, the maximum tension will be expressed by $(2n + 1)$ P tan. a. If the number of the lower horizontal ties is equal, the upper horizontal tie occupying the centre will undergo the greatest tension, and if $2n$ is the number of the lower ties, this maximum tension will be expressed by $2n$ P tan. a.

1481.



In the second place, the case in which the trellis-work beam would be loaded with a weight $2p$ at each of the intermediate joints, B, C, D, and so on, of the lower course of braces. If n is the number of these intermediate joints, $n\,p$ represents the vertical reaction which is exercised at the point A. Considering, step by step, the equilibrium of the upper and lower points of junction, we arrive at the following conclusions:—

1st. The sides parallel to A A′ undergo pressures, having successively for their value $\frac{n\,p}{\cos. a}$, $\frac{(n-2)\,p}{\cos. a}$, $\frac{(n-4)\,p}{\cos. a}$, $\frac{(n-6)\,p}{\cos. a}$, and so on.

2nd. Two inclined ties abutting at the same point, are, the one, compressed, the other extended, by the same intensity.

3rd. The pressures of the upper ties are represented by the values, $2\,n\,p$ tan. a, $4\,(n-1)\,p$ tan. a, $6\,(n-2)\,p$ tan. a, $8\,(n-3)\,p$ tan. a, and so on.

4th. The tensions of the lower horizontal ties are expressed by $n\,p$ tan. a, $[n + 2\,(n-1)]\,p$ tan. a, $[n + 4\,(n-2)]\,p$ tan. a, $[n + 6\,(n-3)]\,p$ tan. a, and so on.

Calling i the position of a horizontal tie in each of these series, we have for the pressure of an upper tie, $2i(n - i + 1)\,p \tan.\, \alpha$, and for the tension of a lower tie,

$$[n + 2(i - 1)(n - i + 1)]\,p \tan.\, \alpha.$$

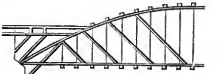
The maximum of the first expression answers to $i = \frac{n+1}{2}$, and that of the second to $i = \frac{n+2}{2}$; if these terms are not integers, the maximum will not be produced exactly, but approximately, although n may be a large number, as is ordinarily the case. We find the value of the maximum to be $\frac{1}{2}\,p \tan.\, \alpha\,(n+1)^2$ in the first case, and $\frac{1}{2}\,p \tan.\, \alpha\,[(n+1)^2 - 1]$ in the second. So that, calling N the number of times that A B is contained in the length of the span, the maximum of pressure or tension of the horizontal ties is expressed by $\frac{1}{2}\,p\,N^2 \tan.\, \alpha$.

There have been constructed in Bavaria timber bridges differing from the American system only in that the joints of all the pieces of woodwork are united by cast-iron sockets, and the girders enter the abutments, hollowed out for this purpose.

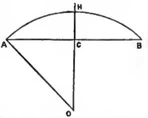
In America there has also been applied another system founded on the use of curved arches. Such is the bridge at Trenton over the Delaware, partially represented in Fig. 1482. The girders are five in number; in each, the principal part is an arc of a circle formed of eight planks superposed; it rests at its extremities upon the piers, and supports the roadway by means of suspending iron bars. The arch is, besides, united to the roadway by pendant ties inclined at an angle of 45°. All the woodwork is covered by a roof, and sheltered laterally by planks. The arches of two successive spans abut against each other by means of woodwork raised upon the pier and elevated to two-thirds of the height of the arches.

Lastly, there has been constructed at Liep, York county, a bridge of the same kind, but in which the roadway, in place of forming the chord of an arc, is placed at mid-height between the chord or the vertex; so that the roadway is suspended underneath the upper portion of the arch, whilst it rests upon its lower portion. This system, in which the bridge forms a girder, appears to offer more resistance.

1482.



1483.



Stone Bridges.—After the water-way has been fixed, we have to determine the dimension and the form of the arches.

There is a very simple relation between the span of a segmental arch, its height or versed sine, and the radius of the circle to which the arc belongs. If $2c$ represents the span, or the chord A B, Fig. 1483, of the arc, f the versed sine H C, and R the radius O A, the semichord A C being a mean proportional between the two segments of the diameter to which it is perpendicular, we have

$$c^2 = f(2R - f), \text{ whence } R = \frac{c^2 + f^2}{2f}. \qquad [1]$$

If we wish to have the semi-arc A H in degrees, or the angle of the centre A O H, we observe that it has for its sine the proportion $\frac{AC}{AO}$ or $\frac{c}{R}$; designating the angle by α, we have then

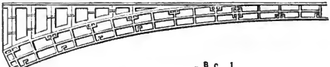
$$\sin.\, \alpha = \frac{2fc}{c^2 + f^2} = \frac{2\frac{f}{c}}{1 + \frac{f^2}{c^2}}. \qquad [2]$$

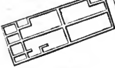
It is not usual to give to the proportion $\frac{f}{c}$ a lower value than $\frac{1}{4}$, which supposes a height equal to $\frac{1}{8}$ of the span, and gives $\sin.\, \alpha = 28°\ 4'\ 20''$, or thereabouts. However, in exceptional cases, this proportion has sometimes been reduced to $\frac{1}{5}$ or $\frac{1}{6}$.

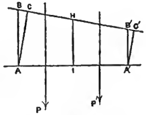
The bridge of Solferino is an example of the form adopted in the early construction of iron bridges. The arches, Fig. 1484, have a span of 40 mètres, and a height of $4^{m}\cdot02$. They are formed of cast-iron voussoirs, of open work in the leading arches and solid in the intermediate. The figure, 1485, represents the elevation and the transverse section of the first voussoir of on intermediate arch. It will be seen that the section represents a double T, with a central rib. The pediment, that is to say, the space comprised between the arch and the roadway, is filled up by open-work plates of a trapezoidal form. Fig. 1486 represents one of these plates.

The girders are united one to another by three systems of cross-joints, placed, some above the ribs of the intrados, others below it, and others upon the ribs which form the crown of the pediment. These latter cross-joints, at a distance of $1^m \cdot 30$, also serve to sustain arches of brick and Roman cement, upon which the roadway and the side-walks are erected. In this system of arches formed of

1484.







1485. 1486. 1487.

voussoirs, the casting is only subject to compression; the only portions exposed to extension are the cross-joints, but as they are few in number they may be executed in wrought iron. The pressures to which the voussoirs are subject can be calculated as for stone arches. But the inequalities of the load are of much greater importance here than in stone bridges. Supposing that one half of the span bears the maximum load of 400 kilos. a square mètre, whilst the other only supports its own weight, we can determine on this hypothesis the direction and intensity of the thrust on the key. Let P and P', Fig. 1487, be the weights supported by the two halves, H the point of application of the reaction N of the two halves of the arch, and B C the oblique direction of this reaction. We let fall from the springs A and A', upon this direction, the perpendiculars A C and A' C', and erect the verticals A B and A' B'. Let p and p' be the distances of the forces P and P' from the points A and A'. We shall have for the equilibrium of the first half of the arch the formula $N \times A\,C = P\,p$, and for the equilibrium of the second half $N \times A'\,C' = P'\,p'$, whence dividing member by member, $\frac{A\,C}{A'\,C'} = \frac{P\,p}{P'\,p'}$. But the triangle A B C and A' B' C' being similar, the first term may be replaced by the proportion of A B to A' B', which gives $\frac{A\,B}{A'\,B'} = \frac{P\,p}{P'\,p'}$, whence $\frac{A\,B}{A\,B + A'\,B'} = \frac{P\,p}{P\,p + P'\,p'}$. Now, calling H the height I H, we have $A\,B + A'\,B' = 2\,H$, consequently there results $A\,B = 2\,H \frac{P\,p}{P\,p + P'\,p'}$, from which we can obtain the direction of the force N, next the distance A C, and ultimately the intensity of the thrust N.

The most remarkable example of a bridge with straight iron beams is the Britannia Bridge, constructed in 1850 over the Menai Straits, by Robert Stephenson, on the Chester and Holyhead Railway. This bridge traverses an arm of the sea at 33 mètres above high water, by means of four spans, of which two are not less than 140 mètres long. This bridge has the form of a long tube, with a rectangular section of $9^m \cdot 144$ in height by $4^m \cdot 50$ in breadth. Its upper casing wall is itself formed of eight equal tubes, fastened one to another, of a square section of $0^m \cdot 533$ a side, and its flooring is formed of six similar tubes $0^m \cdot 533$ high by $0^m \cdot 711$ wide. The lateral walls are solid, and united, both above and below, by triangular brackets $1^m \cdot 22$ high by $0^m \cdot 533$ wide. Since the completion of this work, about which an immense amount of nonsense has been written, bridges with beams of iron plating have multiplied considerably. In bridges of small dimensions the beam is composed of a long plate of sheet iron, made fast at top and bottom by angle-iron; Fig. 1488 gives the section of this beam. It is strengthened from distance to distance by transverse plates having the same height as the beam, and towards the top the same width as the upper plate, while towards the bottom they are of greater width. This form is represented by the dotted lines on Fig. 1488. In the more important bridges, the beam is a tube with a rectangular section, formed of four plates of iron held together by angle-iron. Fig. 1489 is the section of a beam of this kind. The arrangement of these beams has been varied in many ways, those just described are the most generally used. On railways, beams analogous to that of Figs. 1488, 1489 are ordinarily placed above the roadway which rests on the lower ribs; these beams are three in number, and the trains pass along the spaces between them. It follows, when the bridge is of large dimensions and the beams consequently of

1488. 1489.

great height, that the prospect is completely shut out when passing over rivers, that is, at the most picturesque parts of the way. To obviate this inconvenience, the German engineers have endeavoured to replace the solid walls of the beams by walls of trellis-work; but this system, in which one of the sets of bars forming the trellis is elongated while the other is compressed, does not afford sufficient solidity.

To determine the transverse dimensions of straight beams, they are considered as prismatic bodies placed upon two supports, loaded with a weight uniformly diffused, and with a load applied at the centre. If p designates the weight a mètre uniformly diffused, P the load applied at the middle of their extent, x the length of this, R the limit of tension which must not be exceeded, h the height of the bridge, and I the moment of inertia of its upright section in relation to the horizontal drawn in this section through its middle, or, more exactly, through its centre of gravity, we shall have to apply the empirical formula $R = \frac{\frac{1}{2} h}{I}\left(\frac{1}{8} p a^2 + \frac{1}{4} P a\right)$. But it is necessary to observe here that, as in the case of timber bridges, if the load is the weight of two locomotives crossing at the middle of the interspace, as this is an exceptional load, we may admit that the plates, in place of only having to support, as ordinarily supposed, about $\frac{1}{10}$ of the tension corresponding to its limit of elasticity, momentarily supports $\frac{1}{5}$; that is, in place of taking for R 6 kilos. a square mètre, we should take 12 kilos.

1490.

In arched metal bridges, the beams which sustain the flooring are ordinarily of cast iron, in the shape of a double T. But sometimes it is required that the resistance should be the same in all the transverse sections, at least over a certain extent, starting from the key. To this end, the distance between the internal edges of the ribs is made to vary. If, for example, h stands for the distance between the ends A and C, Fig. 1490, b the distance between the points A and B, h' the distance between the points A' and C', and b' twice the distance A' I, h' is made to vary in such a manner that the resistance caused by the weight uniformly diffused may be the same for each section within certain limits.

Let p be the weight uniformly diffused, and a the length of the interspace; each point of support will exercise a reaction equal to $\frac{1}{2} p a$; the moment of the forces which act upon this space, from the point which has for its abscissa x, computed from one of the extremities as far as the other extremity, will have for value $\mu = p(a - x)\frac{1}{2}(a - x) = -\frac{1}{2} p a (a - x)$; or $\mu = -p(a x - x^2)$.

The moment of inertia of the section in relation to the horizontal passing through its centre of gravity is besides, according to an empirical formula, $I = \frac{1}{12}(b h^3 - b' h'^3)$; finally, the ordinate of the most distant rib from the axis is $v = \frac{1}{2} h$.

Calling R the limit of tension not to be exceeded, we shall then have, taking only the absolute value of μ, $R = \frac{v \mu}{I} = \frac{b p (a x - x^2)}{b h^3 - b' h'^3}$, a formula which will give the values of h' corresponding to the values of x. But as it is not necessary that the thickness A A should be less than the thickness of the vertical nucleus, as soon as h' has attained the value that is given for this thickness, we cease adding to h', and diminish h as far as a limit fixed beforehand. On the Anteuil railway, for instance, we have, according to M. Claudel,

$$p = 1600^k, h = 0^m \cdot 60, b = 0^m \cdot 28, b' = 0^m \cdot 26, a = 8 \text{ mètres};$$

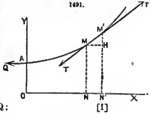
and, taking R, for want of better knowledge, as equal to 6,000,000, we find the value of x corresponding to the key, that is for $x = \frac{1}{2} a h = 0^m \cdot 52$, which will give $0^m \cdot 08$ for the thickness of the two united ribs, or $0^m \cdot 04$ for each of them. We find that for $x = 1^m \cdot 44$ (about), the thickness of each rib is reduced to $0^m \cdot 02$, which is the thickness of the nucleus; h and h' are then diminished by an equal quantity without decreasing the thickness of the rib, until we reach $h = 0^m \cdot 40$, the limit of height fixed beforehand.

The cross-bars are also ordinarily of a double-T section. On the Auteuil railroad we have $a = 2^m$, $h = 0^m \cdot 30$, $b = 0^m \cdot 20$, $b' = 0^m \cdot 188$, whence we deduce $0^m \cdot 014$ for the thickness of the nucleus and the ribs.

Suspension Bridges.—The first consideration in suspension bridges is to determine the geometrical position of the angles of the polygon formed by the points of attachment of the suspending rods. It will be observed, first, that each couple of rods corresponding with the two sides of the roadway may be considered as bearing half the weight of each of the two interspaces comprised between the couple of rods and the preceding or following. If the rods are equidistant, they will consequently sustain equal weights. If the rods were infinite in number and infinitely close to one another, each couple would sustain an element of the roadway, and any given portion of the chain would sustain a weight proportioned to its horizontal projection. On this hypothesis it is easy to perceive that, disregarding the weight of the rods, the chain would assume the form of a parabola to the vertical axis, the equation of which is easily ascertained. Let A, Fig. 1491, be the lowest point of the chain. At this point is exercised a horizontal tension which we will represent by Q. Let us take for the axis of y, the vertical of the point A, and for the axis of x a horizontal O X drawn at the height of the roadway. Let M and M' be two points of the chain infinitely close to one another; let T be the tension of the chain at the point M, a force

which is applied in the direction of a tangent at this point. If a designates the angle of this tangent with the horizon, the horizontal and vertical components of T will be T cos. a and T sin. a. Passing from the point M to the point M', these components will become T cos. a + d, T sin. a, and T sin. a + d, T sin. a.

1491.



Let $2p$ be the weight a lineal mètre of the bridge, $2p\,d\,x$ will be the weight of an element of this bridge, and $p\,d\,x$ will be the weight of the portion N N' of the bridge supported by a rod jointed at the middle of the element M M'. This element being in equilibrium under the action of this weight and of the two tensions already considered, we shall have, by taking the sum of the horizontal components (T cos. a + d, T cos. a) − T cos. a = 0, or d, T cos. a = 0, whence

$$T \cos. a = \text{const.} = Q; \qquad [1]$$

and taking the sum of the vertical components,

$$(T \sin. a + d,\ T \sin. a) - T \sin. a - p\,d\,x = 0, \text{ or } d,\ T \sin. a = p\,d\,x,$$

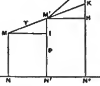
and substituting for T its value $\frac{Q}{\cos.\ a}$, $d\,Q \tan. a = p\,d\,x$, or $Q\,d\,y' = p\,d\,x$, calling y' the angular coefficient of the tangent at M. Integrating and observing that the point A is the lowest point, we have $y' = 0$ for $x = 0$; we obtain $Q\,y' = p\,x$, or $dy = \frac{p}{Q}\,x\,d\,x$. Integrating afresh and designating by y, the ordinate of the point A, we find

$$y - y_0 = \frac{p}{2\,Q}\,x^2, \qquad [2]$$

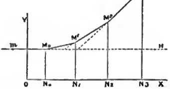
the equation of a parabola which has for axis the axis of y, d being employed as the differential sign.

Without supposing the rods infinite in number, if we suppose them equidistant, as is ordinarily the case, and disregarding their weight, we may demonstrate by very slight consideration that the angles of the polygon formed by the chain are upon a parabola. Let M, M', M'', Fig. 1492, be three consecutive points of the chain; let T and T' be the tensions of the sides M M' and M' M'', and P the weight supported by the rod M' N'. The point M' being in equilibrium under the action of those three forces, the sum of their horizontal components is equal to 0; that is to say, the horizontal projection of the tension of any given side is a constant quantity; we will designate it as above, by Q. Produce the side M M' as far as K; the three forces T, T', and P, will be proportional to the three sides of the triangle M' M'' K, which are respectively parallel to them. If then we represent the tension T by the side M M', or by its equal M' K, the tension T' will be represented by M' M'', and the weight P by M'' K. Now the weight sustained by each rod is a constant quantity, since the rods are equidistant; the length M'' K is then also constant. Draw the horizontals M I and M' H. The length M' I or its equal K H being the primary difference of the ordinate M N; that is to say, the difference between M' N', and M N, and M'' H, being the primary difference of the ordinate M' N', that is the difference between M'' N'' and M' N', the length K, which is the difference between these two primary differences, is nothing else than the second difference of M N. The centre of curvature of the points of the chain has then this property, that the second difference of the ordinate is constant; it is then a curve, the equation of which is in the form $y = a + b\,x + c\,x^2$, that is, it is a parabola, whose axis is parallel to the ordinates.

1492.



1493.



Finally, still disregarding the weight of the rods, whatever may be the successive distances of the rods one from the other, the consecutive points of attachment of the chain are always upon a parabola. Let M_0, M_1, M_2, M_3, ... Fig. 1493, be the consecutive points of the chain; x_0, y_0, x_1, y_1, x_2, y_2, ... their co-ordinates in relation to two rectangular axes, the one vertical passing through the middle of the horizontal side m M_0, and the other horizontal; P_0, P_1, P_2, P_3, the weights supported by the corresponding rods; T_1, T_2, T_3, ... the tensions of the consecutive sides; Q their common horizontal projection. It is sufficient, in fact, to consider the equilibrium of any given apex and make equal to 0 the sum of the horizontal projections of the forces acting upon it, to see that all these tensions have horizontal projections equal in absolute value. Let us consider the equilibrium of the point M_0; the weight P_0 applied at this point has for its expression

$$P_0 = p\left(x_0 + \frac{x_1 - x_0}{2}\right) = \frac{1}{2}\,p\,(x_1 + x_0), \qquad [3]$$

designating by p the weight a linear mètre sustained hy the chain, which is the half of the weight per linear mètre of the roadway. Making equal to 0 the sum of the horizontal projections of the forces Q, T, and P_0, we ehtain

$$Q = T_1 \cos. M_1 M_0 H = T_1 \frac{x_1 - x_0}{M_0 M_1}.$$

Making equal to 0 the sum of the vertical components of the same forces, we find

$$\frac{p}{2}(x_1 + x_0) = T_1 \sin. M_1 M_0 H = T_1 \frac{y_1 - y_0}{M_0 M_1}.$$

If we divide term hy term the two proportions just estahlished, we ehtain

$$\frac{1}{2} \frac{p}{Q}\ x_1 + x_0) = \frac{y_1 - y_0}{x_1 - x_0}, \text{ whence } y_1 - y_0 = \frac{p}{2\,Q}(x_1^2 - x_0^2). \qquad [4]$$

If we consider the equilibrium of the point M_1, we shall find in the same way

$$Q = T_2 \frac{x_2 - x_1}{M_1 M_2} \text{ and } \frac{p}{2}(x_2 + x_1) = T_2 \frac{y^2 - y}{M_1 M_2},$$

whence dividing term by term,

$$\frac{p}{2\,Q}(x_2 + x_1) = \frac{y_2 - y_1}{x_2\, x_1}, \text{ or } y_2 - y_1 = \frac{p}{2\,Q}(x_2^2 - x_1^2). \qquad [5]$$

Applying the same method to all the other points, we shall ohtain analogous relations; and if x_{n-1}, y_{n-1}, and x_n, y_n represent the co-ordinates of any two given consecutive points, we shall have

$$y_n - y_{n-1} = \frac{p}{2\,Q}(x_n^2 - x_{n-1}^2). \qquad [6]$$

Adding term to term all the relations thus obtained, and reducing, we find

$$y_n - y_0 = \frac{p}{2\,Q}(x_n^2 - x_0^2),$$

so that by suppressing the index n we have for any given point of which x and y are the co-ordinates,

$$y - y_0 = \frac{p}{2\,Q}(x^2 - x_0^2); \qquad [7]$$

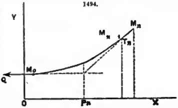
this is the equation of a parabola whose axis is vertical, and which has for its vertex the point of the axis of y having for its ordinate $y_0 - \frac{p}{2\,Q} x_0^2$.

If the chain had no horizontal side, we should make the y axis pass through the lowest apex M_0; we should then have $x_0 = 0$, and applying the same method, we should find the equation of the parabola to be

$$y - y_0 = \frac{p}{2\,Q} x^2. \qquad [8]$$

Having the equation of the curve, we can easily deduce from it the horizontal component Q of the tensions of the sides. In fact, the point at which the chain meets the vertical, elevated at the extremity of the roadway, may be considered as a point of the chain; now this point is always given. If the chain is symmetrical with relation to the lowest point, the co-ordinates of this imaginary point of attachment are the semi-span a of the bridge, and the height h of this point above the axis x; we should then have, in the case of the formula [7],

1494.



$$h - y_0 = \frac{p}{2\,Q}(a^2 - x_0^2), \text{ whence } Q = \frac{1}{2}\, p\, \frac{(a^2 - x_0^2)}{h - y_0}.$$

In the case of the formula [8], we should have

$$Q = \frac{1}{2}\, p\, \frac{a^2}{h - y_0}.$$

Thus, by assuming the supposed point of attachment, and the point M_0, we determine the ordinate of a point of the chain corresponding with a given abscissa, and consequently the point corresponding with a given rod, as well as the horizontal tension of the chain.

The actual point of attachment is always situated beyond the point which we have called the imaginary point of attachment.

It is easy to deduce from the preceding the tension of a given side of the polygon formed hy the chain. Let M_{n-1} and M_n, Fig. 1494, be two given consecutive points, and T_n the tension of the side M_{n-1} M_n. The portion of the chain comprised between the point M_0 and the point M_{n-1} bears the weight of the roadway comprised between the axis of y and the vertical passing through the middle of M_{n-1}, M_n; this weight has then the value

$$P_n = p\left(x_{n-1} + \frac{x_n - x_{n-1}}{2}\right) = \frac{1}{2}\, p\,(x_{n-1} + x_n).$$

This portion of the chain is in eqnilihrium under the action of its weight, and of the forces Q and T_n; calling a_n the angle of the side M_{n-1} M_n with the horizon, and making equal to 0 the

sum of the horizontal components and that of the vertical components of these three forces, we obtain $T_n \cos. a_n = Q$, and $T_n \sin. a_n = P_n$, whence, squaring, adding, and extracting the square root:

$$T_n = \sqrt{Q^2 + P_n^2}. \qquad [9]$$

This tension increases with P_n; thus the maximum of tension is placed on the last side. In order to calculate it more easily, we may suppose that the lowest point of the chain is the vortex of the parabola, which is to place it in the case of the formula [8]; and if we call b the difference $h - y_o$, or the height of the point of attachment above the lowest point, we have

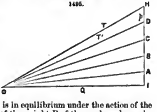
$$Q = \frac{1}{2}\, p\, \frac{a^2}{b}.$$

Besides, we have then $P = p\,a$; calling T the maximum tension, it follows that

$$T = \sqrt{p^2 a^2 \frac{1}{4} p^2 \frac{a^4}{b^2}}, \text{ or } T = p\,a \sqrt{1 + \frac{a^2}{4\,b^2}}. \qquad [10]$$

The horizontal tension and that of the different sides of the chain may also be determined geometrically when we know the inclination of the last side. To make this clear, we will take the case where there is a horizontal side. Upon a vertical of indefinite length let us take the lengths I A, A B, B C, ... D H, Fig. 1495, proportional to the successive weights supported by the different rods; that is to say, to half the sum of the weights of the two adjacent divisions of the bridge. From the point I draw a horizontal, and from the extreme point H a right line, having the inclination given by the last side of the chain. These two right lines meet at a point O; draw O A, O B, O C, ... O D. The right line I H, representing the weight borne by the rods O I, will represent the horizontal tension Q, and the lines O A, O B, O C, and so on, will represent the tensions of the successive sides of the chain; O H will represent the tension of the last side, which is the maximum tension. If we first consider the portion of chain comprised between the first rod and the last, we see that it is in equilibrium under the action of the horizontal tension Q of the tension T of the last side, and of the weight P of the roadway borne by these rods. Now, these three forces being parallel to the three sides of the triangle O I H, they are proportional to these sides; and since P is represented by I H, it follows that Q is represented by O I, and T by O H.

1495.



Let us now consider the point of attachment of the last rod; it is in equilibrium under the action of the weight p, suspended to the rod, of the tension T of the last side, and the tension T' of the preceding side. Now, the two former forces being represented in magnitude and in direction by the two sides D H and O H of the triangle O D H, the third force T' must be represented in magnitude and in direction by the third side O D of this triangle. We should thus demonstrate step by step that O C, O B, O A, and so on, represent in magnitude and direction the successive tensions of the other sides. An analogous mode of reasoning would be employed in case there were no horizontal side. In both cases the force Q is the horizontal projection common to all the tensions.

It is necessary to determine the length of the chain. To obtain this, we might calculate successively each of its sides by means of the co-ordinates of its extremities. But this method is a very laborious one; and we can obtain a sufficient approximation by substituting for the polygon the circumscribed parabola, of which we have the equation. We take for this the equation [8], in which we suppress y_o, which amounts to making the x axis pass through the lowest point; we thus get $y = \frac{p}{2\,Q} x^2$, or, replacing Q by its value, $\frac{1}{2}\, p\, \frac{a}{b}$,

$$y = b\,\frac{x^2}{a^2}. \qquad [11]$$

Calling s the length of the arc of the curve computed from the vertex, we have

$$ds = dx\sqrt{1 + y'^2};$$

but $y' = 2\,b\,\frac{x}{a^2}$, consequently $ds = dx\sqrt{1 + \frac{4\,b^2\,x^2}{a^4}}$.

In the ordinary application, b is small in comparison with a; besides, x is at the most equal to a; the fraction under the radical is then very small; and we may, without perceptible error, add under the radical $\frac{4\,b^4\,x^4}{a^8}$; the quantity under the radical then becomes a perfect square number, and extracting the root, we obtain $ds = dx\left(1 + \frac{2\,b^2\,x^2}{a^4}\right)$.

Integrating, and observing that for $x = 0$ we should have $s = 0$, we find

$$S = x + \frac{2}{3}\,\frac{b^2\,x^3}{a^4},$$

and for $x = a$,

$$s = a + \frac{2}{3}\,\frac{b^2}{a} = a\left(1 + \frac{2}{3}\,\frac{b^2}{a^2}\right), \qquad [12]$$

which is the length of the parabola from the lowest point up to the point which corresponds with the extremity of the roadway.

This length of the chain is its absolute length under the action of the load which it supports; it is greater than its original length s_0 by the elongation produced by tension. Let θ be a mean between the maximum tension calculated above, and the horizontal tension Q; the elongation of iron a linear mètre being 0·00005-mètre for a tension of 1 kilogramme a square millimètre of the section, calling ω the section of the chain expressed in square millimètres, $s - s_0 = s_0 \frac{\theta}{\omega} 0^m \cdot 00005$,

whence $s_0 = \frac{s}{1 + \frac{t}{\omega} 0 \cdot 0005}$. The length s will vary with the temperature; the coefficient of the expansion of iron, roughly estimated, is 0·0000122, so that passing from 0 to the temperature t, the length s becomes $s' = s(1 + 0 \cdot 0000122\, t)$. From this results an increase of the versed sine, which it is necessary to know how to calculate. Now, if in the formula [12] we allow s and b to become variables and differentiate, we have $ds = \frac{4\,b}{3\,a} db$. For in considerable expansions we may admit that the final increments of s and b are plainly proportional to increments infinitely small; we then write

$$\Delta s = \frac{4\,b}{3\,a} \Delta b, \quad \text{whence } \Delta b = \frac{3\,a}{4\,b} \Delta s, \qquad [13]$$

. Δb signifies the finite difference of b.

This formula gives the increment of the versed sine Δb corresponding with an increase of length Δs of the chain. We thus find that for a bridge of 100 mètres span, in which case a is equal 50 mètres, and having a versed sine of 5 mètres, the latter is augmented by $0^m \cdot 135$ when the temperature is raised from 0 to 30°.

The section of the rods is easily calculated according to the weight they have to carry. Take the value of the weight of the roadway which the rod has to support, and add to it, according to the regulations laid down, a load of 200 kilos. a square mètre; divide the sum by 12 kilos. in the case of iron bars, and by 18 kilos. in the case of wire rope. The quotient expresses in square millimètres the section of the rod.

The section of the chain is determined according to the maximum tension which it has to support. This tension is obtained by taking into account at first only the weight of the roadway, of its load, and of the weight of the rods. We thus obtain for the section of the chain an approximative value, whence we deduce the approximative value of the chain itself. Recommencing the calculation by introducing into the total weight that of the chain, we obtain a near value for the section, which is in general sufficiently near for all purposes. The small beams supported by the rods by means of iron straps may be considered as prisms placed upon two supports and loaded with the weight of the flooring-planks, which form two semi-interspaces, having the regulation load or weight uniformly spread over the length of the beam. The dimensions of the flooring are calculated in a similar manner. The regulation load of 200 kilos. a square mètre represents the weight of three men. If the bridge is intended for the passage of vehicles, it is necessary, in the calculation of the section of the chain and that of the rods, to take into account the weight of two conveyances at least; and to consider them as crossing one another upon a given interspace. It is also necessary to consider this circumstance in the calculation for the smaller beams and the floor, independently of a weight uniformly distributed; we have then to consider a weight applied at a given point, for example in the middle, which is the most unfavourable case.

We require to calculate the lengths of the rods. If they are not equidistant, each of these lengths must be calculated by means of the equation of the parabola, and taking the sum. But the calculation is simplified when the rods are equidistant. Let us consider first the case in which there is no horizontal side. We have seen that the equation of the parabola in relation to its vertex is then $y = b\,\frac{x^2}{a^2}$.

Let us designate by λ the width of an interspace; the successive lengths of the rods, computed from the axis of x, that is to say, from the horizontal which starts from the lowest point, will have for their respective values $\frac{b\,\lambda^2}{a^2}$, $\frac{b\,4\,\lambda^2}{a^2}$, $\frac{b\,9\,\lambda^2}{a^2}$, ... $\frac{b\,n^2\,\lambda^2}{a^2}$, calling n the number of rods. The sum Σ of these rods will then be $\Sigma = \frac{b\,\lambda^2}{a^2}(1 + 4 + 9 + \ldots + n^2)$. Now the sum of the squares of the consecutive numbers from 1 to n has for its value $\frac{n(n+1)(2n+1)}{6}$, we shall then have $\Sigma = \frac{b\,\lambda^2}{a^2}\,\frac{n(n+1)(2n+1)}{6}$.

We may simplify still more this expression by observing that we have

$$a = (n + 1)\lambda, \text{ whence } \frac{\lambda}{a} = \frac{1}{n+1}.$$

Substituting this value for $\frac{\lambda}{a}$, and reducing, we find

$$\Sigma = b\,\frac{n(2n+1)}{6(n+1)}, \text{ or } \Sigma = \frac{1}{3}\,b\,n\,\frac{2n+1}{2n+3}. \qquad [14]$$

If there is a horizontal side, the most simple method is still to take the parabola in relation to its vertex, in which case the equation [8] is reduced further to the form $y = \frac{p}{2\,Q}\,x^2 = b\,\frac{x^2}{a^2}$, since the transposition of the axis of x does not change the parameter. But the abscissa of the points

of attachment of the rods are then, designating by ϵ, the half-interspace, ϵ, 3ϵ, 5ϵ, 7ϵ, ..., $(2n-1)\epsilon$, n designating the number of the rods. We have then in this case

$$\Sigma = \frac{b\,\epsilon^2}{a^2}\,[1 + 9 + 25 + 49 \ldots . + (2n-1)^2].$$

Now the sum of the squares of the n first unequal numbers has for its value $\frac{(2n-1)\,2n\,(2n+1)}{6}$,

we then get $\Sigma = \frac{b\,\epsilon^2}{a^2}\,\frac{(2n-1)\,2n\,(2n+1)}{6}$.

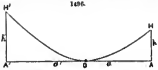
This expression may be simplified by observing that we have $a = \epsilon\,2n + 1$, whence $\frac{\epsilon}{a} = \frac{1}{2n+1}$. Substituting and reducing, we obtain as a final result

$$\Sigma = b\,\frac{(2n-1)\,2n}{6\,(2n+1)} = \frac{1}{3}\,b\,n\,\frac{2n-1}{2n+1}. \qquad [15]$$

We may remark that the values of Σ given by the formulæ [14] and [15] differ very slightly from $\frac{1}{3}\,b\,n$; so that when we only require a summary estimate, we can get the sum of the lengths of the rods by multiplying the third of the greatest by the number of these rods.

The formulæ [14] and [15] give the sum of the lengths of the rods only as far as the tangent to the vertex of the parabola circumscribed on the chain. It is necessary to add further the lengths of the portions of the rods comprised between the tangent and the roadway. If the latter is horizontal, calling δ the distance from the vertex of the curve to the roadway, we must add $n\,\delta$ to the sum already calculated. Sometimes the roadway has a slightly parabolic form, the convexity being turned upwards. In this case it would be necessary further to add to the sum of which we speak the sum of the ordinates of the new parabola, corresponding with the same abscissæ; they are calculated like the first sum.

1496.



We have supposed up to the present that the chain was composed of two symmetrical portions, its vertex corresponding with the middle of the roadway. This is not always the case; but, knowing the heights h and h', Fig. 1496, of the supposed points of attachment H and H' above the tangent to the vertex, and the length A A' = L of the roadway, it is easy to determine the distances a and a' from the summit of the parabola to the extremities of this roadway. For we have, first, $a + a' = L$. Next we have, since the points H and H' are upon the parabola, $h = \frac{p}{2Q}\,a^2$ and $h' = \frac{p}{2Q}\,a'^2$,

whence $\frac{h}{h'} = \frac{a^2}{a'^2}$, or $\frac{a}{a'} = \frac{\sqrt{h}}{\sqrt{h'}}$.

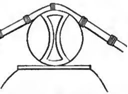
We also obtain from the two relations between a and a' the values

$$a = L\,\frac{\sqrt{h}}{\sqrt{h} + \sqrt{h'}},\ \text{and}\ a' = L\,\frac{\sqrt{h'}}{\sqrt{h} + \sqrt{h'}},$$

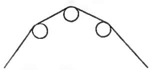
which determine the position of the point O. This point being known, we may apply to each of the branches O A and O A' the calculations and the formulæ belonging to the case in which the point O was supposed to be in the middle of the roadway.

We have also supposed that there was only one chain on each side of the bridge; generally there are several; but the projection of their vertices upon a vertical plane parallel to the direction of the bridge is upon the same parabola. The calculations are made as if all these vertices belonged to one chain. If there are four, the first bears the rods 1, 5, 9, &c.; the second, the rods 2, 6, 10, &c.; the third, the rods 3, 7, 11, &c.; the fourth, the rods 4, 8, 12, &c.

1497.



1498.

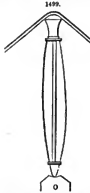


The chains or cables rest upon the piers or abutments by means of fixed or movable supports. In the first case, these supports are piers of masonry, or cast-iron pillars. The chains are not attached to these; they pass over rollers, or portions of rollers, known as revolving sectors, Fig. 1497, which themselves rest upon a plane surface. The intention of this arrangement is to distribute the pressure more equally over the different portions of any one chain, and to counteract the rupture which might result from an inequality of tension between two consecutive portions of the chain. Occasionally the chain is even made to pass over three rollers, of which one, that in the middle, is placed higher than the others, in order to diminish the angle of flexion of the chain, Fig. 1498.

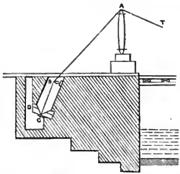
The movable supports are columns or large cast-iron uprights, resting upon a fixed support by means of a horizontal rounded edge. This arrangement has the same intention as the use of friction-rollers or revolving sectors. The tension is distributed equally between the two divisions of the cable, and the resultant of the two equal tensions is directed according to the bisectrix of the angle formed by the two divisions; it leans towards one or the other side, according to the inequality of the load of the two roadways. It is plain that if, from the effect of a passing load upon one of these two roadways, the tension of the chain is augmented, the chain is drawn towards that side, and by adherence draws with it the movable pillar, making it revolve round its resting point O, Fig. 1499, until the tension diminishing on that side and increasing on the other, becomes equal to the two divisions.

The base of the pier must be so arranged that, meeting the result of the two tensions, with the weight of the pier and the revolving column, we obtain a total resultant which meets the base of the pier at a point in its interior, sufficiently removed from the nearest edge to avoid crushing the stone, and will also make with the vertical an angle inferior to the angle of the friction of the pillar on the stone, that is to say, inferior to 37°, or the *angle of friction*.

1499.



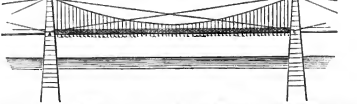
1500.



Each of the extremities of the chain, after having passed over the fixed or movable support which corresponds to the abutment, is carried into the ground, penetrating into a solid mass of masonry, united to the pier. Fig. 1500 shows this arrangement; the chain after passing over the support, takes the direction A B, generally more nearly approaching the vertical than the last side T A; at B it assumes a bent direction, so as not to require in the mass where it is moored dimensions needlessly great; with the point of inflection there usually corresponds a smaller revolving support; the chain afterwards descends in the direction B C into an inclined channel, which is terminated by a narrow opening closed by a plate of cast iron, to which the chain is fixed; below this is the mooring-hole C, into which there is access by the opening D to reach the point of attachment. The same opening usually serves for access to the two cavities on the same bank communicating one with another by a vaulted gallery. It is necessary for the equilibrium and stability of the system, that on composing the tension in the direction of A B with the weight of the mooring-block, a resultant should be obtained which meets the mass of the block at a point in its interior, at a sufficient distance from the nearest ridge, and which will make, with the vertical, an angle inferior to the *angle of friction* considered above. In accordance with this, the dimensions and consequently the weight of the block are determined.

As a rule, no great height is given to the supports, whether fixed or movable; it follows that the tension Q is rather considerable, for it varies in inverse ratio with the height; but in an economical point of view there is less inconvenience in slightly augmenting the section of the chains, than in increasing the height of the supports, which would besides have the effect of

1501.



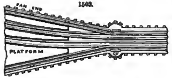
diminishing stability. Where we are obliged to give a great height to the supports, they are united by stays A B, C D, Fig. 1501, which are attached to the top of one of the piers and fixed at the foot of the other: the figure shows this arrangement.

We have said that the actual point of attachment of the chains does not coincide with that which we have called the imaginary point of attachment, which is upon the vertical of the extremity of the roadway. In this interval, the chain having only its own weight to carry, affects the form of an arch of chainwork, which accords with the parabola circumscribed on the chain; but the two curves differ then so little one from the other, that we may without appreciable error consider the arch of chainwork as the prolongation of the parabola.

Iron Bridge Building.—The Charing Cross Bridge, erected to support the Charing Cross Railway over the Thames, occupies the site of the Hungerford Suspension Bridge.

This bridge comprises nine spans, Fig. 1502, six of 154 ft. and three of 100 ft. The superstructure over the three latter spans is fan-shaped, Fig. 1503, inasmuch as the ground available for the Charing Cross Station being somewhat restricted in length, it was necessary to begin the widening out on the bridge. It was found necessary to divide the opening between the Middlesex pier and abutment into three spans of 100 ft., instead of into two spans of 154 ft., as on the Surrey side.

1503.



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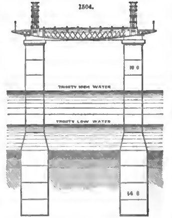
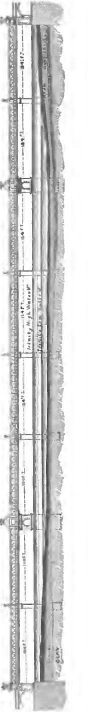


The bridge is carried by cylinders, sunk into the bed of the river, and by the piers of the Hungerford Suspension Bridge, Fig. 1502, the upper portions of which have been removed, while the lower portions have been added to and modified, so as to adapt them for the railway bridge. The abutments of the Hungerford Suspension Bridge are also retained, but have been considerably lengthened and altered. The width of the river at the bridge is 1350 ft. The greatest depth of water between the two brick piers is 13 ft. below low-water spring tides, and the average depth is about 10 ft. The rise of spring tides is 17½ ft. The level of the rails is 31 ft. above Trinity high-water mark, and the clear minimum headway is 25 ft. above the same level.

1502



This bridge was designed by Hawkshaw, but the practical part of the work, which is by far the most considerable portion, is due to the engineering skill of Joseph Phillips.

Cylinders for the Openings 154 ft. Span.—The cylinders, excepting those at the fan end, are 14 ft. diameter below, and 10 ft. diameter above the ground, the junction between the two sizes being effected by an intermediate conical length, Fig. 1504. There are four piers (three intervening between the towers of the Hungerford Suspension Bridge and one between the tower and the abutment on the Surrey side) formed of cylinders of the above diameters, and each of the piers consists of two cylinders, 49 ft. 4 in. apart, from centre to centre. They are of cast iron, and are shown in detail in Figs. 1505 to 1507. The circumference of each cylinder of 14 ft. diameter, is divided into seven equal parts or segments, the segments being generally 9 ft. high; that of the cylinders 10 ft. diameter, is divided into five equal parts or segments, each segment being also generally 9 ft. high; whilst that of the intermediate or conical piece is similarly divided into five equal parts or segments, each 9 ft. high. The segments are fastened together inside, by bolts 1¼ in. diameter, passing through flanges cast on the top, bottom, and sides of the segments. A horizontal interior strengthening rib is cast on the middle of each segment. All the joints of the segments, both horizontal and vertical, are planed, and spaces are left inside between the flanges for the introduction of iron cement, to render the joints water-tight. The vertical joints of the segments, in each of the two lengths of different diameters respectively, are over one another. There are thus continuous vertical lines of ribs, securing a strong columnar arrangement. The

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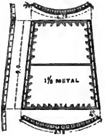

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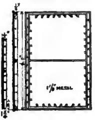
1507.



horizontal joints can also be made to fit better in this way than by breaking the vertical joints. The thickness of the metal in these cylinders is $1\frac{1}{8}$ in. throughout, excepting in the bottom length, where it is $1\frac{1}{4}$ in.

Sinking the Cylinders.—The staging for sinking the cylinders consisted of piles erected round the pier, supporting a stage or platform at the level of 4 ft. above high-water mark. When this staging was in its place, an opening of 45 ft. was left between two adjoining piers; but in order that the navigation might not be interrupted, only two openings, in the space between the two

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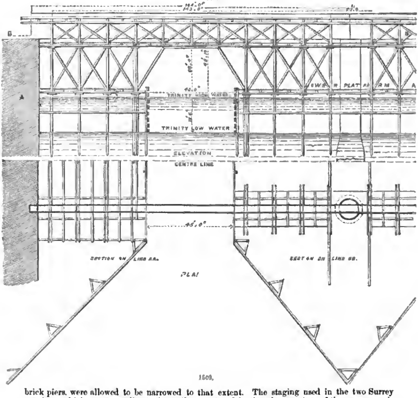


1509.

brick piers, were allowed to be narrowed to that extent. The staging used in the two Surrey openings, which was generally similar to that employed for the other openings of the same span, is shown in Figs. 1508, 1509. The part up to the lower platform was erected for the purpose of sinking the cylinders. This was afterwards carried up, and the 45-ft. opening spanned, for the purpose of erecting the girders.

The strata through which the cylinders are sunk, Fig. 1502, consist of mud and gravel, of varying thicknesses, overlying the London clay. The cylinders were sunk by excavating the material from the inside, by means of divers, and then by weighting them as the excavation proceeded, until they had passed through all the porous material, and had entered a few feet into the solid London clay. The water was then pumped out, and the cylinder was kept dry during the rest of the operation. The sinking was then proceeded with, by excavating the material and by weighting the cylinders. The weight with which it was found necessary to load the cylinders, in order to overcome the friction of the sides, and to sink them to their final depth, averaged about 150 tons. The London clay extended to a depth far below the level at which the cylinders were founded.

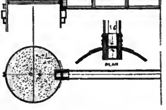
The cylinders constituting the pier between the Surrey abutment and the brick pier, are sunk to a depth of 52 ft. below Trinity high-water mark. Those between the two brick piers are sunk to a depth of 62 ft. below the same level, excepting the up-stream cylinder of the middle pier, which had to be sunk 10 ft. deeper, on account of some of the material through which it passed being softer than that met with at the sites of the other cylinders.

Filling-in the Cylinders, and Weighting.—After the cylinders had been sunk, and the material had been excavated, they were filled with concrete up to where the conical part commences, and with brickwork from that level to the under-side of the granite bearing-blocks occupying the top of each cylinder. The concrete was composed of Thames gravel or ballast, that obtained from the excavation from the inside of the cylinders being used, so far as it was suitable and sufficient. This was mixed with Portland cement, in the proportion of one part of cement to seven parts of gravel. The brickwork is generally composed of the best paviour bricks, set in Portland cement mortar, in the proportion of one part of cement to two parts and a half of sand.

Before the lengths above high water were put on, the cylinders, after they had been filled with the concrete and brickwork, were weighted with a load of about 450 tons, excepting the two cylinders in the pier nearest to the Surrey side, which were the first sunk, and weighted each with 700 tons, that being about the greatest load that could come upon any one cylinder, assuming the four lines of rails on the bridge to be loaded with locomotive engines. Upon the removal of the loads, it was found that each of the cylinders which had been weighted with 700 tons had permanently sunk 4 in., and each of the others that were loaded with 450 tons had permanently sunk, on an average, nearly 3 in. The larger loads were applied in order to test the strength of the foundations, and the subsequent smaller loads to bring the cylinders to a bearing, so as to prevent any settlement, after the completion of the bridge, from the weight of the permanent and moving loads. The load was applied by piling the permanent rails of the railway on the cylinders. After it was removed, the top lengths were put on, and were filled in with brickwork, and then the granite bearing-blocks were fixed in place. These blocks are 2 ft. 6 in. thick, and are in two equal pieces, which, when together, fill the cylinder, the joint being under and longitudinal with the girders. The granite blocks project 1 in. above the top of the cylinders, in order that the weight may be prevented from coming on the upper edge of the ironwork.

Each pair of cylinders forming a pier is connected together transversely by a wrought-iron box-girder, 4 ft. deep, strongly attached to the top of each, Figs. 1510 to 1512. This girder also serves the purpose of a cross-girder for supporting the roadway. Assuming the four lines of way on the bridge to be loaded with locomotive engines, the pressure on the base of the cylinders would amount to about 8 tons the square ft., and that on the brickwork at the top of the cone, where the cylinder is 10 ft. diameter, to about 9 tons the square ft. The former pressure, however, is on the supposition that no relief is afforded by the friction of the sides against the material through which the cylinders penetrate. If this were taken into account, as it should be, the 8 tons the square ft. would be much reduced, and it is clear that this pressure will not be approached.

1510.



1511. 1512.

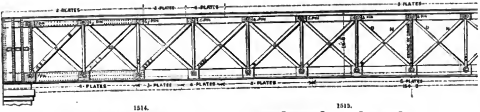
Superstructure of the Openings 154 ft. Span.—The superstructure of each of the openings, 154 ft. span, consists of two main girders, underneath which are cross-girders, Fig. 1504. The main girders are, like the cylinders, 49 ft. 4 in. apart from centre to centre transversely, leaving a space between them sufficient for four lines of rails, the roadway platform being supported by the cross-girders. For the purpose of carrying the footpaths, each of which is 7 ft. wide, the cross-girders extend beyond the main girders, forming a series of cantilevers on each side of the bridge.

Main Girders Spanning the 154-ft. Openings.—These girders are of wrought iron. They are not continuous over two or more openings, but are all detached. Each has to support, inclusive of its own weight, a maximum distributed load of about 700 tons. The elevation, sections, and details of these girders are shown in Figs. 1513 to 1530. The extreme depth of the girders is 14 ft., and the depth between the centres of gravity of the top and bottom members is 12 ft. 9 in. When the girders are loaded with a maximum strain of 4 tons the sq. in. in compression, and of 5 tons the sq. in. in extension (which are the limits allowed for the wrought-iron work throughout the bridge), the sectional area in the top, at the centre of the girder, will be somewhat less than 300 sq. in., and that in the bottom, excluding the rivet-holes, will be somewhat less than 235 sq. in.; these being the respective central areas of the girders.

The sides of the girders between the bearings are divided by vertical bars into fourteen equal

parts, each division containing a double set of two diagonals crossing each other. These are placed, as nearly as practicable, at an angle of 45° with the top and bottom of the girder; and both the diagonals and the vertical bars are connected to the top and bottom webs by pins of puddled

1513.



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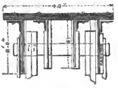

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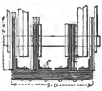

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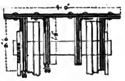
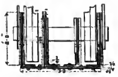


1528.



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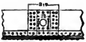

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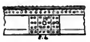


steel. The top and bottom webs of the girders are of boiler-plate, and consist of horizontal tables 4 ft. wide at the top and 3 ft. wide at the bottom, and of four vertical ribs, the two outer rows being 24 in. deep, and the two inner 21 in. deep. The joints of the plates, in the horizontal tables

of the top and bottom webs, are covered by a continuous plate running the whole length of the girder; that in the top being of the same thickness as the plates covered, and that in the bottom $\frac{1}{16}$ in. thicker, Figs. 1525 to 1528. The joints in the vertical ribs in the top and bottom occur near the pin-holes, and are covered by 1-in. plates, 2 ft. 4 in. long, placed on both sides of the ribs, thus forming a good bearing for the pins, Figs. 1529, 1530. The vertical ribs are united to the horizontal tables by angle-iron, 6 in. by 6 in., by 1 in. thick in the centre and $\frac{3}{4}$ in. thick at the ends, covered at the joints. The rivets used throughout the top and bottom of the girders are 1 in. diameter, and their pitch is about 4 in.

The aggregate thickness of the plates in the horizontal table of the top in the centre of the girder being $3\frac{1}{2}$ in., and in the bottom $3\frac{11}{16}$ in., without the angle-iron, and $4\frac{1}{2}$ in. and $4\frac{11}{16}$ in. respectively, with the angle-iron, but excluding the angle-iron covers, it would not be easy to unite the parts composing such a thickness by rivets passing through holes punched in the metal. However perfectly the holes may be set out in the first instance, the process of punching always stretches the iron; so that, when the plates are put together, the holes do not come accurately over one another. Neither would they have been truly cylindrical throughout, as they are always, when punched, larger on one side than the other; so that where so many thicknesses had to be united, imperfect riveting would have resulted, unless rimering out to a great extent had been resorted to.

The diagonals which act as ties are of Heward's rolled suspension links, each separate tie being composed of two or three links riveted together. The diagonals acting as struts are each in one solid forging. The struts and the ties have swelled ends for the pins. The struts are united together in pairs, by zigzag bracing of wrought iron, $4\frac{1}{2}$ in. wide by $\frac{3}{8}$ in. thick, riveted to them, and by bolts passing through cast-iron distance-pipes. The ties, also in pairs, are not united together; but in the centre of the girders, where the diagonals act both as struts and ties, the pairs are united together in the two central spaces by the zigzag work. The dimensions of the struts vary from 12 in. by 3 in. at the ends, to 6 in. by $2\frac{1}{2}$ in. in the middle; and of the ties, from 12 in. by $2\frac{1}{2}$ in. at the ends, to 6 in. by 2 in. in the middle. They are 7 in. diameter at the ends of the girders, decreasing to 5 in. diameter at the centre, and are 11 ft. apart from centre to centre.

At the ends of the girders the sides over the supports are boxed, being composed of $\frac{1}{2}$-in. plate iron, stiffened by angle and T iron. Where the girders bear upon the brick piers and upon the Surrey abutment, they rest upon roller bed-plates; but upon the cylinders sheet lead only is interposed between the girders and the granite blocks. The force of expansion and contraction will probably cause the cylinders between the brick piers to rock to and fro to a certain but inappreciable extent. The girders were put together in place on the staging, Figs. 1508, 1509. The top of the girder was put together on the top upper platform, and the bottom of the girder on the top lower platform, the two platforms being kept at the correct distances apart by diagonals, converting the whole into a framework of timber. The supports on the platforms, on which the girders were erected, were accurately adjusted to the proper camber of the girders.

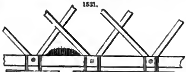
The struts, with the diagonal bracing, were also put together at the works of Cochrane and Co., and the pin-holes were bored out to the full size; so that they, and also the ties, were sent up in a complete state. When the top and bottom webs were in place, the struts and the ties were erected, and the pin-holes in the girders were accurately bored out, by means of a boring apparatus worked by a small steam-engine, the gauge of the running wheels of which was so adjusted, that it might work backwards and forwards on the two outer vertical ribs of the lower part of the girder. Great care was taken to ensure accuracy in the direction and position of the holes. The pins, after being coated with grease, were forced into the holes, the diameter of the latter being such that the former could only be driven in by exerting a considerable force, a perfect fit being thereby established. The vertical bars dividing the sides into the several spaces are 6 in. wide by 1 in. thick. They have not been taken into account in calculating the strains. They fit on to the ends of the steel pins, and are in pairs, one on either side, and outside the outer vertical ribs of the top and bottom, and are connected together by bolts and distance-pipes. The only use they serve is to stiffen the girder.

The ends of the pins are covered with circular castings, screwed on; and over the ends, resting on the cylinders, ornamental castings are fixed.

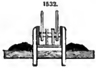
The weight of each main girder spanning the 154-ft. openings is 190 tons.

One of the main girders was tested, when in place, with a distributed load of 400 tons, and the deflections were accurately taken. The load being very great, and the girder being unconnected transversely (the cross-girders not having been fixed), great care had to be observed in putting on the weight, which consisted of the rails of the railway. The manner in which it was loaded will be understood from Figs. 1531, 1532. The greatest deflection in the centre, when the

1531.



1532.

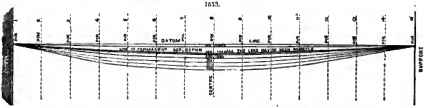


load was on, was $1\frac{1}{16}$ in., and the permanent deflection, after the load was removed, was $\frac{1}{4}$ in., Fig. 1533. If the girders had been rigidly connected transversely by the cross-girders, the deflection would doubtless have been less. This has since been proved to be the case. The whole of

the bridge, in its completed state, has been tested by a maximum load, and the greatest deflection of the main girders has not been more than ¾ of an in. in the centre.

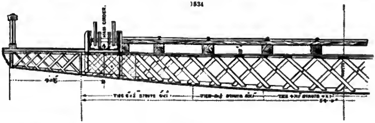
The plate iron used throughout the bridge was also tested. These are interesting, as both the extension and the permanent set were carefully taken by an accurate *extensometer*.

1533.

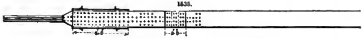


It has been before stated that the girders are all detached, and not continuous over two or more openings. Hawkshaw's original intention was to connect the girders spanning the two end openings on the Surrey side, and also to connect the girders spanning the four central openings. As regards the girders spanning the two openings on the Surrey side, it was found that it was not easy to gain the full advantage from continuity, inasmuch as the girders having to support a considerable load, the thickness of the plates in the top and bottom was too great to render it practicable to reduce them to a minimum at the point of contrary flexure. Moreover, the strain on the diagonals would have been greater at the central support than at the end supports, and the uniformity in size of the struts and ties could not have been maintained, had their correct dimensions consequent upon continuity been adopted. It was also desirable not to increase the strain on the diagonals, as the end struts are already large forgings. The same remarks apply, more or less, to the girders spanning the four central openings, although in this case greater advantage would have been gained by continuity. More difficulty, however, would have been experienced in their erection, inasmuch as the Conservators of the River Thames only allowed the staging to be erected in the river for two of the central openings at one time. It is clear, also, that much more trouble would have been incurred in constructing continuous girders over several openings, than in putting together a series of detached girders. In the former case there would be a multitude of dissimilar parts, whilst in the latter all the girders would be duplicates of one

1534



1535.

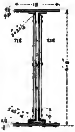


another. Better workmanship is thus ensured, and at a less cost a ton. In order to ascertain whether any saving of metal would be effected by the girders being constructed on the continuous or non-continuous system, drawings of both were prepared, and the weights were accurately calculated. The difference was inconsiderable in the case of the side openings, and was not of sufficient importance over the central openings to counterbalance the advantages to be derived from non-continuity.

Cross-girders for the Openings 154 ft. Span.—The cross-girders for the openings, 154 ft. span, are shown in Figs. 1534 to 1537. They are of wrought iron, and are suspended from the main girders. The top and the bottom of that portion of the cross-girders between the main girders consist of two plates, 18 in. wide by ½ in. thick. The sides are of lattice-bars, united to the top

1536.

1537.



and bottom by two angle-irons, 5 in. by 3 in. by $\frac{7}{16}$ in. thick. These cross-girders are 4 ft. deep in the middle and 2 ft. 1½ in. deep where the cantilevers are united to them outside the main girders,

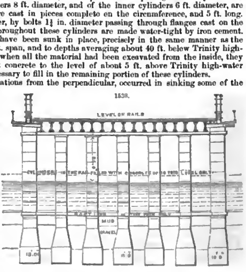
the bottom being fish-bellied, and the top having a camber of 3½ in. in the centre. The lattice-bars are fixed at an angle of about 45° with the top and bottom. The ties are in two bars throughout, and each bar varies from 6 in. by ½ in. at the ends to 4 in. by ½ in. in the middle. The struts are in one bar passing between the two ties, and vary from 6 in. by 1 in. at the ends to 4 in. by 1 in. in the middle. The rivets in the cross-girders are 13/16 in. diameter. The cantilevers decrease from 2 ft. 1½ in. deep at their junction with the cross-girders to 1 ft. 2 in. deep at the extremities. The top and bottom of the cantilevers are composed of two angle-irons, 3½ in. by 3 in. by ½ in. thick, and the sides are of lattice-bars also placed at an angle of about 45° with the top and bottom; the ties likewise consist of two bars and the struts of one bar passing between them, each of the former being 2 in. by ⅜ in. and the latter 2 in. by ⅝ in.

It will be seen, therefore, that the cross-girders are generally similar in character to the main girders. They are suspended from the under-side of the main girders at the points where the pins occur. They are therefore placed 11 ft. apart, from centre to centre. The sides of the cross-girders, where they are underneath the main girders, are boxed in with plate iron. They are suspended by four angle-irons—two on either side—and outside the outer vertical ribs of the bottom of each main girder, to which, and to the boxed sides of the cross-girder these angle-irons are riveted. By this means a strong and good attachment is established. The cross-girders are connected together by wrought-iron cross-bracing attached to the centre of each, Fig. 1503. Each cross-girder, including the two cantilevers, weighs 9 tons. They were tested by erecting two cross-girders in the contractor's yard, placed transversely 6 ft. apart in the clear, the cantilevers being removed. They were then loaded with 140 tons (equivalent to 70 tons on each girder) distributed over the span. The maximum deflection in the centre, when the load was on, was 1 in.; and the permanent deflection, when the load was removed, was ¼ in. This result would doubtless have been better had the cross-girders been in place and rigidly fixed at the ends to the main girders. The whole of the cross-girders have since been tested in place with a maximum load, and the deflection has in no case been more than ⅜ in. in the centre.

Fan End.—The superstructure of the three openings, 100 ft. span each, of the fan end is supported by the Middlesex brick pier and by the Middlesex abutment of the bridge, and intermediate to these by piers of cast-iron cylinders, that next to the brick pier consisting of a row of seven cylinders, and that next to the abutment of a row of nine cylinders. In these two rows, Figs. 1503, 1538, the outer cylinders are 10 ft. diameter below and 8 ft. diameter above the ground, and the inner ones are also 10 ft. diameter below but only 6 ft. diameter above the ground, the junction between the two lengths of different diameters being effected by a conical length. The circumference of the lower lengths of the cylinders, 10 ft. diameter, is divided into segments, which are generally similar, and are connected together in the same way, as the upper lengths of the cylinders already described, of the same diameter, in the piers of the openings 154 ft. span. The upper lengths of the outer cylinders 8 ft. diameter, and of the inner cylinders 6 ft. diameter, are not divided into segments, but are cast in pieces complete on the circumference, and 5 ft. long. These pieces are fastened together, by bolts 1¼ in. diameter passing through flanges cast on the top and bottom. All the joints throughout these cylinders are made water-tight by iron cement. The cylinders in these two piers have been sunk in place, precisely in the same manner as the cylinders of the openings of 154 ft. span, and to depths averaging about 40 ft. below Trinity high-water mark. When in place and when all the material had been excavated from the inside, they were filled with Portland cement concrete to the level of about 5 ft. above Trinity high-water mark. It was not considered necessary to fill in the remaining portion of these cylinders.

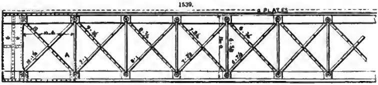
As some irregularities, or deviations from the perpendicular, occurred in sinking some of the cylinders in the row next the Middlesex brick pier, a horizontal casting, extending over all the cylinders of this row, was bolted to them at about the level of the ground, Fig. 1538; on this casting the upper parts of the cylinders of this pier are fixed.

1538.



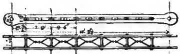
On account of the great width of fan, which increases from 49 ft. 4 in. from centre to centre of the outside girders at its commencement at the Middlesex brick pier (this being the width between the parallel main girders spanning the 154-ft. openings) to 168 ft. from centre to centre of the outside girders at the abutment, the system pursued in the other openings, of supporting the roadway on cross-girders suspended from outside main girders, was clearly inadmissible. It was also undesirable to introduce intermediate main girders, projecting above the roadway. The roadway over the fan is, therefore, carried by interior plate-girders, laid at right angles to the piers and the abutment, and by the outside main girders, which are at the angle of inclination of the fan. These latter, Figs. 1539 to 1542, are of the same depth, and although lighter in all the parts, are generally of the same character, and are fixed at the same level, as the girders

1539.

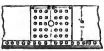


1540.

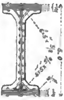
1541.



1542.



1543.



of the openings 154 ft. span. The faces of the bridge have, therefore, a uniform appearance throughout.

The interior plate-girders, where they bear on the cylinders, rest on a bed-plate, Figs. 1503 to 1543, extending over all the cylinders of each row. They are connected together by cross-bracing in the centre of each span, and at points intermediate between the centre and the supports; and where they rest on the Middlesex pier and abutment are built into the brickwork. The bottom of these girders is at a lower level than the bottom of the outside main girders, inasmuch as it was impossible to obtain sufficient depth without resorting to this arrangement. As it is, the depth of these girders is only 5 ft., or $\frac{1}{20}$ of the span. If the spans in the fan had been 154 ft., the interior plate-girders instead of being $\frac{1}{20}$ would have been less than $\frac{1}{31}$ of the span. Hence the advantage of introducing the smaller spans of 100 ft. The elevations and sections of the interior plate-girders are shown in Figs. 1543, 1544. They are of the ordinary construction, and weigh about 26 tons each.

1544.

The outside main girders do not make exactly the same angle with the centre line produced of the parallel portion of the bridge. The shape of the fan is therefore not accurately that of an isosceles triangle—the distance between the centre line of the fan and the centre line produced of the parallel portion of the bridge, being 7 ft. 9 in. at the Middlesex abutment, Fig. 1503. These outside main girders, which are over the centre of the outside cylinders of the piers, are raised above the interior plate-girders by cylindrical making-up pieces of the same diameter (8 ft.) as the upper lengths of the outside cylinders, Fig. 1538. These cylindrical pieces are filled with brickwork in cement, resting on the bed-plate, the top being covered with a bed of an inch in thickness of Portland cement, raised $\frac{1}{8}$ an in. above the top of the cylinder, and forming the bearing surface of the girders.

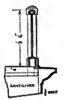
The triangular spaces between the outside main girders and the outer interior plate-girders are filled in with cross-girders, riveted to the sides of the latter and suspended underneath the former, and are terminated by cantilevers projecting beyond the face-girders, Figs. 1503, 1538. These cantilevers are similar to those outside the main girders of the 154-ft. openings, and like them are placed about 11 ft. apart from centre to centre, thus preserving the uniformity.

The girders of the fan rest directly on their supports, no rollers being interposed, excepting underneath the outside main girders, where they rest on the Middlesex brick pier and abutment; but the bearings for the interior plate-girders on the cast-iron bed-plate over the cylinders are planed. The ends of the cylinders on which the bed-plate rests are also planed.

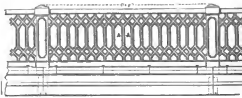
Roadway and Footpath Platforms.—The roadway platform over the openings 154 ft. span, consists of planking 4 in. thick, spiked to longitudinal timbers, 15 in. by 15 in., placed underneath the rails, and bolted to the cross-girders. The roadway platform over the fan end consists of planking 6 in. thick, secured to the interior plate-girders and to longitudinal timbers spanning the cross-girders in the triangular spaces. By abandoning the longitudinal timbers in the fan over the shallow interior plate-girders, which the arrangement permitted, additional depth was obtained for these. The footpath platform on each side consists throughout of planking 6 in. thick, secured to the top of the cantilevers. The roadway platform is covered with tar pavement about 2 in. thick, and the footpath platforms with asphalte 1 in. thick. The longitudinals and the whole

of the planking are creosoted, and the latter is grooved and tongued with iron, and caulked with tar and oakum. The rails over the bridge are flat-bottomed, and of the ordinary section. On the outside of the footpath an ornamental railing, of cast-iron, is fixed, Figs. 1545 to 1548. A

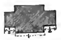
1545.



1546.



1547.

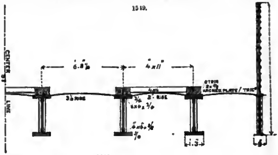


1548.

railing of a pattern generally similar is fixed to the main girders on the inside of the footpaths, to prevent the railway being trespassed upon.

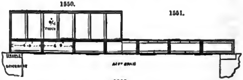
On the Charing Cross railroad there are several small iron bridges, many similar to Broadwall Bridge, Figs. 1549 to 1553. This bridge consists of six inner working girders and two face-girders with a light parapet riveted to the upper flange. It has a span of 41 ft., and the depth of the girders is 2 ft. 6 in.; top flange, 16 in. wide by $\frac{5}{8}$ in. thick, riveted to web by two angle-irons, 4 in. × 4 in. × $\frac{5}{8}$ in., and pierced with holes for $\frac{7}{8}$ rivets every 3 in. on each side; bottom flange, 15 in. wide by $\frac{7}{8}$ in. thick, riveted to web by two angle-irons 4 in. × 4 in. × $\frac{5}{8}$ in.; web, $\frac{1}{2}$ in. thick in seven sections, connected at vertical joints by two ┳-irons, 5 × 2$\frac{1}{2}$ × $\frac{1}{2}$.

1549.



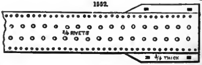
At each end of girder there is a bearing-plate. For face-girder, top flange, 9 in. wide by $\frac{1}{2}$ in. thick, not centred with web, to which it is connected by two angle-irons 3 × 3 × $\frac{1}{2}$.

1550. 1551.



The girders in this bridge are braced by a system of diagonal bars, 3 in. × $\frac{5}{8}$ in., connected to girders by means of short pieces of ┳-iron, riveted to top and bottom of webs about 6 ft. 8 in. apart.

1552.



In addition to the ordinary angle-iron cover, a strip is riveted to the opposite side of the girder.

The weight of the six working girders is 26$\frac{1}{4}$ tons; of the two face-girders, 4$\frac{3}{4}$ tons; and of the whole bridge, 43 tons.

1553.

Wellington Street Bridge.—This, on the same line, is the largest single-web girder bridge on the line, the length of the girders being 134 ft., and the span on skew 118 ft. The girders are 12 ft. deep at centre, and 9 ft. 8 in. at the ends.

The flanges are 2 ft. 6 in. wide, riveted with six rows of 1-in. rivets. The top flange is built up of five $\frac{5}{8}$ plates at centre, reduced to three at ends. In addition to the two angle-irons which connect this flange to web, there are two others of the same size, 5 × 5 × $\frac{11}{16}$, riveted to each edge, Figs. 1554, 1555. The bottom flange is built up of one $\frac{11}{16}$ and four $\frac{5}{8}$ plates, reduced at ends to one

$\frac{11}{16}$ and two $\frac{5}{8}$ plates. On each side of the upper side of this flange a bar, 9 in. × $\frac{11}{16}$, is riveted. This is shown in Figs. 1554 to 1558. Fig. 1558 shows the way the plates break joint.

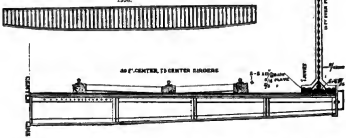
The web-plates, with the exception of the end ones, are 2 ft. 2 in. wide, the end ones being 2 ft. wide, as shown in Fig. 1558, $\frac{5}{8}$ thick for a length of nine plates at either end, and $\frac{7}{16}$ for the remaining distance.

1555.

1554.

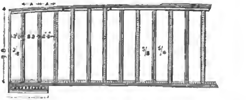
Referring to Figs. 1556 to 1558, it will be seen that a $\frac{1}{2}$ plate is riveted to the ends of the girders by means of angle-iron *gussets*, 3 in. × 3 in. × $\frac{3}{8}$ in.; also, that at the two end web-joints $\frac{1}{2}$ *gusset*-plates are riveted, with similar angle-iron. After the bridge was erected, it was found necessary to stiffen the ends of the girders by

1556.



1557

1558.



attaching reverse angle-iron, 3 × 3 × $\frac{1}{2}$, to the end and *gusset* plates. The intermediate vertical joints of web are connected by two T-iron gussets, 6 × 3 × $\frac{1}{2}$, and two strips, 6 × $\frac{1}{2}$ alternately. These strips, as shown in Fig. 1551, are cranked to set over the longitudinal angle-iron.

One end of each girder was provided with a bearing-plate, 5 ft. × 4 ft. × $\frac{3}{4}$; the other end had attached to it a cast-iron plate, 2 in. thick, to bear on eight rollers, $4\frac{1}{2}$ in. diameter. The roller-beds are also of cast iron, 2 in. thick, and further strengthened by having three ribs, 3 in. deep, cast on; the roller-frames are of wrought iron, 3 in. × 1 in.

A longitudinal section of this roller arrangement is shown in Fig. 1558, and a transverse section in Fig. 1557.

In Fig. 1558 the lengths of top and bottom angle *covers* are shown by the number of rivets in each. The first have seven and eight holes in each arm respectively, and the second nine and ten; so that, since the rivets are 4-in. pitch, the lengths are 2 ft. 8 in. and 3 ft. 4 in.

The ordinary lengths of

Angle-bars	13 ft.	Joints to flat bars	3 ft. 4 in.
Flat bars, 9 × $\frac{11}{16}$	17 ft. 4 in.	Laminated plates	6 ft. 8 in.

The dimensions A A, Fig. 1558, are 16 in. each, so that they contain four rivets in the direction of length of girder each. Considering one plate only, since there are six rows of rivets, we have an aggregate of twenty-four 1-in. rivets, or a sectional area of 18·84 sq. in. against 14·76 sq. in., the sectional area of a bottom plate through a line of rivet-holes; or an excess in area of rivets of 4·08 sq. in.

The cross-girders are 41 ft. 6 in. long, which makes the distance, centre to centre, of main girders 39 ft. The distance, centre to centre, of the cross-girders themselves, is 4 ft. They have a central and end depth of 2 ft. and 1 ft. 4 in.; the flanges are 15 in. × $\frac{1}{2}$, connected to a $\frac{1}{2}$ web by 4 × 4 × $\frac{3}{8}$ angle-iron. The top flange has also riveted to it an extra plate, 19 × $\frac{1}{2}$, for attaching roadway plate. Fig. 1555 is a section of one of the girders, showing a road-plate attached at B. The length of the girder is divided into eight panels by vertical T-irons at joints, 5 × $2\frac{1}{2}$ × $\frac{3}{8}$.

At each end of the bridge there are also shorter cross-girders; but they are the same as a 41 ft. 6 in. girder, with a piece cut off one end. The ends of the cross-girders are riveted to the mains with twenty-four rivets, 1 in. diameter.

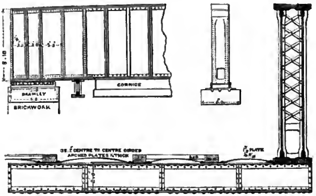
To the ends of the cross-girder, a cast-iron cornice, C, Fig. 1554, is bolted.

The rivets through longitudinal angle-iron and webs are 1 in. diameter, and through vertical

T-irons, strips, and webs, only ¾ in. diameter. The weight of each main girder is 65 tons: of all the cross-girders, 80 tons; and of the whole bridge, 248 tons.

Bridge over the Blackfriars Road, Figs. 1559 to 1561.—One of the abutments of this bridge is at right angles to line, and the other only slightly out of square.

1560. 1561. 1559.



The main box-girders, which are 110 ft. long, have a central and end depth of 10 ft. 6 in. and 8 ft. 10 in.: both flanges are 2 ft. 6 in. wide; the top is built up of five $\frac{9}{16}$ plates at centre, reduced to four at ends; the bottom is built up of one ½ and four $\frac{9}{16}$ plates at centre, reduced to one ½ and three $\frac{9}{16}$ at ends. Each flange is connected to the webs by four angle-irons $6 \times 6 \times \frac{9}{16}$: eight in the whole section.

The two end web-plates at either end of each line are 2 ft. wide, and the intermediate ones are 3 ft.

The girders are braced internally at seven points by a system of lattice-bars, shown in Fig. 1559; the bars are $2 \times \frac{1}{2}$, and are riveted to T-irons, which, in this case, are substituted for the internal strips.

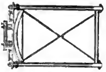
The cross-girders, twenty-four in number, have flanges 15 in. wide × ½ thick, riveted to a ½ web by $4 \times 4 \times \frac{1}{2}$ angle-iron: they are 2 ft. deep, and each end is riveted to the main girder with twenty 1-in. rivets; the web is divided by vertical T-irons into eight panels.

The weight of both main girders is 106½ tons; of all the cross-girders, 71 tons 12 cwt.; and of the whole bridge, 214 tons 17 cwt.

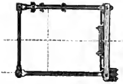
The roadway is on the second system, Fig. 1559.

The constructive arrangement of the bridge, exhibited in Figs. 1562 to 1569, introduced by Albert Fink, is a modification of the principles employed by Bollman. In this bridge a pair of diagonal tension-bars connect the foot of the principal strut, or *king post*, in each truss, with the ends of the top chord. This pair of diagonal bars support one half of the whole weight of the truss and its load. Each half-span is subdivided by a strut, and two diagonal tension-bars extend, one to the nearest end of the top chord, and the other to the top of the centre post. Each quarter-span is again subdivided into eighths, and these again, for spans greater than 100 ft., into sixteenths. In a truss of this kind, of sixteen panels, the weight at the bottom of the strut nearest to either of the piers is distributed thus:—Calling the weight one, one half is transferred directly through a tension-rod to the nearest end of the top chord, and to the pier. The other half is carried up to the top of the second strut from the pier, and is received at the bottom of that strut by a pair of tension-rods, which divide this half between them, one fourth being taken directly to the nearest pier, while the other fourth is transferred to the top of the strut at the quarter-span. This fourth is again divided at the foot of this strut, one eighth being transmitted through a tension-rod to the nearest pier, while the other eighth passes to the top of the middle strut of the span, and is received at the foot of this strut by the main tension-rods, each of which transmits one-sixteenth of the original load to each pier. Thus the weight at the foot of the first strut from the end of the truss is distributed thus:—One-half, one-fourth, one-eighth, and one-sixteenth, or, in all, fifteen-sixteenths of that weight reach the top of the nearest pier, through four converging sets of tension-rods, while the remaining sixteenth reaches the opposite pier, after being brought to the foot of the centre strut, through the intervention of three separate systems of tension-bars. With the exception of the load at the foot of the centre strut, which load is transmitted directly to the piers, the loads at the bottoms of the vertical struts are more or less subdivided before reaching the ends of the truss. In 1852, A. Fink erected a bridge of three spans, of 205 ft. each, across the Monongahela River, Figs. 1562 to 1569. The trusses for a single line are 16 ft. apart from centre to centre, and the main tension-chords are attached to the foot of the centre strut, 22 ft. 8 in. below the centre of the top chord, thus giving a depth of truss equal to 0·11 of the span. The top chords and the centre struts are of cast-iron pipes, octagonal in their external form, 12 in. diameter between their parallel surfaces, and 10 in. in internal diameter, thus giving 41 sq. in. of section. The main tension-rods in each truss are each formed of six bars, 4½ in. by 1¼ in., giving

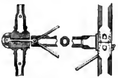
1563.



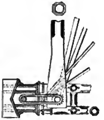
1565.



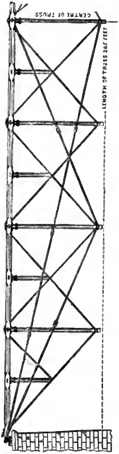
1569.



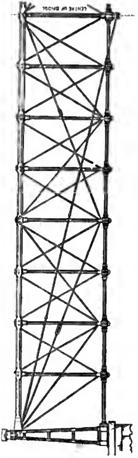
1568.



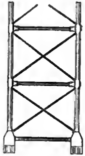
1562.



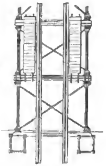
1564.



1567.



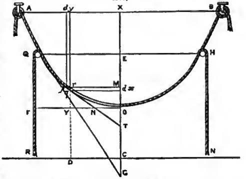
1566.



a section of $33\frac{3}{4}$ sq. in. The vertical struts, with the exception of the centre strut, are cast-iron octagonal pipes, 8 in. in external and 7 in. internal diameter.

Chain and Suspension Bridges.—Suppose a perfectly flexible chain or cord of uniform density and thickness to be suspended from two fixed points, A and B, Fig. 1570, and when in equilibrium to form the curve A O B; this curve is termed the *Catenary*. The equations of this curve, of so much importance in mechanics, being of a mixed exponential kind, mathematicians were obliged to resort to guessing and all sorts of dodges, to obtain results which were often very far from the truth. The results here referred to can now be obtained with the greatest ease by direct processes of the *dual calculus*, in an endless variety of ways, without the use of tables. It may be necessary to inform the reader, that here, as elsewhere, we accommodate those inexperienced in such inquiries with solutions under simple forms easily intelligible.

1570.



To find the Equations of the Catenary Curve.—Let O be the lowest point of the chain or cord A O B, Fig. 1570, O M = x; M r = y; and the length of the arc O r = s. Again, let v be the length of a portion of the chain, the weight of which is equal to the tension at O. If we suppose the part O r rigid, after it has assumed the form of equilibrium, it will evidently be supported in the same manner, and the tensions at O and $p\,q\,r$ will be the same as when it swung loosely suspended from the points A, B. O $p\,q\,r$ is therefore kept at rest by three forces, namely, the tension at O acting in the direction of the tangent O Y, the tension at the point $p\,q\,r$, acting in the direction of $p\,q$ T, the tangent to the curve at the point $p\,q\,r$, and the weight of the piece of cord or chain O r, acting in a vertical direction. Because the three forces just described are respectively in the directions to the three sides of the triangle T p M, the forces being in equilibrium will be proportional to these sides.

Hence, (Weight of O r) : (Tension at O) :: T M : M p. $p\,q\,r$ represent a very small right-angled triangle, similar to the larger right-angled triangle T M p; in the language of the differential calculus $q\,r$ is represented by $d\,x$, $r\,p$ by $d\,y$, and $p\,q$ by $d\,s$. Whence, v being put for a piece of cord or chain, the weight of which is equal the tension at O in the direction of the tangent O Y; therefore, $s : v :: d\,x : d\,y \quad \therefore \frac{d\,y}{d\,x} = \frac{v}{s}$.

In every plane curve $(d\,s)^2 = (d\,x)^2 + (d\,y)^2$, and, consequently, $\frac{d\,s}{d\,x} = \left(1 + \frac{d\,y^2}{d\,x^2}\right)^{\frac{1}{2}}$.

$\therefore$ In the *catenary* $\frac{d\,s}{d\,x} = \frac{\sqrt{v^2 + s^2}}{s}$, or $d\,x = \frac{s\,d\,s}{\sqrt{v^2 + s^2}}$.

Taking the integral of this last equation, and observing that $s = o$ when $x = o$, we obtain

$$x + v = \sqrt{v^2 + s^2}, \quad \text{or } s^2 = x^2 + 2\,v\,x. \qquad [1]$$

When v is determined, [1] is the equation of the *catenary* expressed by x and s as variables.

Again, because $\frac{d\,y}{d\,x} = \frac{v}{s} = \frac{v}{\sqrt{x^2 + 2\,v\,x}}$, which, being integrated, gives

$$\frac{y}{v} = \log._{\epsilon} \frac{x + v + \sqrt{x^2 + 2\,v\,x}}{v}$$

$$\therefore \quad \epsilon^{\frac{y}{v}} = \frac{x + v}{v} + \frac{\sqrt{x^2 + 2\,v\,x}}{v}. \qquad [2]$$

ϵ being put for the base of the hyperbolic system of logarithms, [2] is an equation to the curve between the variable co-ordinates x and y; v being unknown, but constant. The dual logarithm of $\epsilon = 10^8$, written $\downarrow(\epsilon) = 100000000$, $\epsilon = 2{\cdot}718281828 \ldots$

Transposing $\frac{x + v}{v}$, and squaring both sides of [2], we obtain

$$\epsilon^{\frac{2y}{v}} - 2\,\epsilon^{\frac{y}{v}}\left(\frac{x + v}{v}\right) + \frac{(x + v)^2}{v^2} = \frac{x^2 + 2\,v\,x}{v^2}$$

$$\therefore \quad x + v = \frac{v}{2}\left(\epsilon^{\frac{y}{v}} + \epsilon^{-\frac{y}{v}}\right). \qquad [3]$$

Further, because, [1] $s^2 = (x + v)^2 - v^2$, and $\frac{v^2}{s^2} = \frac{v^2}{x^2 + 2\,v\,x}$; $\therefore \left(\epsilon^{\frac{y}{v}} - \frac{x + v}{2}\right)^2 = \frac{s^2}{v^2}$

$$\therefore \quad s = \frac{v}{2}\left(\epsilon^{\frac{y}{v}} - \epsilon^{-\frac{y}{v}}\right). \qquad [4]$$

[4] is an equation to the *catenary* between the variables s and y; it is to be particularly observed that v is unknown in [1], [2], [3], [4], but not variable. Suppose t to be the length of a portion of the cord or chain which is equal to the tension of Q, then $OE = x$, $EQ = y$, $OQ = s$, and $t : s :: QG : GE :: ds : dx$ $\therefore$ $s\,ds = t\,dx$. Differentiating [1], or $s^2 = x^2 + 2vx$, gives $s\,ds = x\,dx + v\,dx$ $\therefore$ $t\,dx = x\,dx + v\,dx$; dividing by dx gives $t = x + v$.

Now, suppose the tension at Q to be balanced by means of QR, a portion of the chain passing over a pulley at Q and hanging freely; then $QR = x + v = OE + v$; consequently, $FR = YD = OC = v$, evidently a constant quantity, although unknown. Hence, if the tension be supposed to be balanced by means of portions of the chain or flexible body hanging over pulleys at the points $p\,q\,r$, Q, A, the lower ends will be in the same horizontal line, R, D, C.

Ques.—A heavy flexible chain, each foot in length weighing 20 lbs., is suspended at its extremities to two fixed points in the same horizontal line, 106·2 ft. asunder, the greatest depth of the curve being 15·8 ft. It is required to find the length of the curve, the tension at the lowest part, and the tensions at the points of suspension, by direct calculation, without the use of tables, or methods of approximation.

In dual arithmetic we have three corresponding numbers, namely, natural number, dual number, and dual logarithm; any one of these corresponding numbers being given, the other two may be found by a few simple additions and subtractions.

We have first to put equation [3] in form to be operated upon by dual arithmetic.

$$x + v = \left(\epsilon^{\frac{y}{v}} + \frac{1}{\epsilon^{\frac{y}{v}}}\right). \qquad [3]$$

When y is put $= 1$, x may be represented c^2, x and y being both given to find the value of v.

Hence [3] becomes $2c^2\left(\frac{1}{v}\right) + 2 = \epsilon^{\frac{1}{v}} + \frac{1}{\epsilon^{\frac{1}{v}}}$

$$\therefore\ 2c^2\left(\frac{1}{v}\right) = \epsilon^{\frac{1}{v}} - 2 + \frac{1}{\epsilon^{\frac{1}{2v}}} = \left\{\epsilon^{\frac{1}{2v}} - \frac{1}{\epsilon^{\frac{1}{2v}}}\right\}^2 \ \therefore\ c\sqrt{2}\left(\frac{1}{v}\right)^{\frac{1}{2}} = \epsilon^{\frac{1}{2v}} - \frac{1}{\epsilon^{\frac{1}{2v}}};\ \text{or,}$$

$$2c\left(\frac{1}{2v}\right)^{\frac{1}{2}} = \epsilon^{\frac{1}{2v}} - \frac{1}{\epsilon^{\frac{1}{2v}}}.$$

Putting $\frac{1}{2v} = z$, the last becomes

$$2c\sqrt{z} = \epsilon^{z} - \frac{1}{\epsilon^{z}}. \qquad [5]$$

This question being the first of the kind solved by an independent and direct process, without employing tables or approximate methods of trial and error, it is therefore necessary that we should be particular with respect to details.

The dual logarithm of 2 is the whole number 69314718, written $\downarrow$, (2) = 69314718,. This logarithm is of the ascending branch, marked by a comma on the right of the logarithm below, and immediately after the arrow. The dual logarithm of the reciprocal of 2· or of $\frac{1}{2}$ is represented by the same whole number '69314718, and written, $\downarrow$, ($\frac{1}{2}$) = '69314718; this logarithm is of the descending branch, marked by a comma to left of the logarithm above. When 69314718, is considered positive, '69314718 is considered negative, and *vice versâ*.

Natural Numbers.	Dual Numbers.	Dual Logarithms.
2·00000000 ·50000000	↓ 7, 2, 6, 0, 7, 8, 2, 6, ↑ '6 '6 '0 '6 '8 '2 '0 '2	69314718, '69314718

$$\downarrow, (10) = 230258509, \text{ and } \downarrow, \left(\frac{1}{10}\right) = {}'230258509;$$

the same notation and arrangement is applied to other natural numbers and their reciprocals. See the Editor's works on Dual Arithmetic.

In the question before us, $c^2 = \frac{15 \cdot 8}{53 \cdot 1} = \cdot 29755178907$;

$\therefore$ $\downarrow$, (2 c) = $\downarrow$, (1·09096616) = $\downarrow$, 0, 8, 7, 4, 6, 4, 5, 5, = 8706369, and [5] becomes

$$\epsilon^{z} - \epsilon^{\frac{1}{z}} = 1 \cdot 09096616\sqrt{z} \quad \downarrow, (\epsilon) = 10^8 = 100000000.$$

Then, putting u_1, for the first dual digit of $z \downarrow, (\epsilon)$, and $'u_1$ for the first dual digit of the logarithm of $- z \downarrow, (\epsilon)$ the reciprocal to $z \downarrow, (\epsilon)$; $'u_1$ is nearly $= u_1$, but less than u_1.

To place this matter in a clear light, it is only necessary to observe that

If x = ↓ 1, 0, 0, 0, 0, 0, 0, 0, then $\frac{1}{x}$ = ↓ '1 1, 0, 1, 0, 0, 0, 1, ; (9531018,).

„ x^2 = ↓ 2, 0, 0, 0, 0, 0, 0, 0, „ $\frac{1}{x^2}$ = ↓ '2 2, 0, 2, 0, 0, 0, 2, ; (19062036,).

„ x^3 = ↓ 3, 0, 0, 0, 0, 0, 0, 0, „ $\frac{1}{x^3}$ = ↓ '3 3, 0, 3, 0, 0, 0, 3, ; (28593054,), and so on.

$$\downarrow, (x) = \downarrow, (1\cdot 1) = \downarrow, 1, 0, 0, 0, 0, 0, 0, 0, = 9531018;$$

$$\downarrow, \left(\frac{1}{x}\right) = \downarrow, \left(\frac{1}{1\cdot 1}\right) = \downarrow, '1\ 1, 0, 1, 0, 0, 0, 1, = '9531018; \text{ and so on.}$$

These things being premised, we have

$$1 + \downarrow [u_1 \ldots\ldots - (1 - \uparrow [u'_1 \ldots) = 2\,c\,\sqrt{z} = 2\sqrt{u_1 \times (\cdot 9531018)};$$

bnt since u_1 is nearly equal to u'_1, in order to find a convenient value for u_1 tho last equation may be put under the form, $+\ 2\left(\frac{u_1}{10}\right) = 2\,c\,\sqrt{u_1 \times (\cdot 09531018)}$

$$\therefore \quad \frac{u_1^{\,2}}{100} = c^2\,u_1\,(\cdot 09531018);\ \text{or } u_1 = 100\,c^2\,(\cdot 09531018);$$

which gives $u_1 = (\cdot 29755\ldots)\,(100)\,(\cdot 0953\ldots) = 2\cdot 835\ldots.$ Because $2\cdot 835\ldots$ is less than a convenient value for u_1, bnt greater than the corresponding value of u'_1; consequently $\downarrow 3$, is a convenient value for u_1. By pursuing a similar process of reasoning, z as far as the fourth dual digit will be found to be equal $\downarrow 3, 0, 3, 4, u_5$; the next step gives the fonr succeeding digits, and at the same time develops the general plan of operating on such equations; besides, any mistake that may be made in the preceding operations will be detected.

$$\downarrow, (1\cdot 33553107) = \downarrow, 3, 0, 3, 4, 0, 0, 0, 0, = 28932904,$$

Reciprocal, $'28932904 = \uparrow, '2\,'7\,'8\,'2\,'5\,'1\,'6\,'5 = \downarrow, (\cdot 74876579)$. Putting z_1 for the dual logarithm of $\downarrow 3, 0, 3, 4, u_5, \ldots$ divided hy 10^8, or $z_1 = \cdot 28932904 + \cdot 00001000\,u_5$; now equation [5] becomes

$$\epsilon^{z_1} - \frac{1}{\epsilon^{z_1}} = 2\,c\,\sqrt{\cdot 28932904 + \cdot 00001000\,u_5} = 2\,c\,\sqrt{\cdot 28932904}\ \sqrt{1 + \cdot 00003803\,u_5} =$$

$$(\downarrow 0, 8, 7, 4, 6, 4, 5, 5,)\ \sqrt{\cdot 28932904}\,(1 + \cdot 00001902\,u_5) = \cdot 58682320\,(1 + \cdot 00001902\,u_5)$$

$$\begin{array}{r|l} \cdot 58682 & 320 \\ \hline & 587 \\ & 528 \\ & 1 \\ \hline & 1116 \end{array} \qquad \left\{\begin{array}{l}\text{because } 1 + \cdot 00001902 \text{ may} \\ \text{be taken for the square root} \\ \text{of } 1 + \cdot 00003803.\end{array}\right\}$$

$\cdot 00001116$ for $\cdot 00001902$

$$\therefore \quad 2\,c\,\sqrt{\cdot 28932904 + \cdot 00001000\,u_5} = \cdot 58682320 + \cdot 00001116\,u_5$$

$$\epsilon^{z_1} - \frac{1}{\epsilon^{z_1}} = 1\cdot 33553107\,(1 + \downarrow [u_5) - \cdot 74876579\,(1 + \uparrow [u'_5 \ldots);$$

$$1\cdot 33553107\,(1 +, \downarrow [u_5 \ldots) \text{ may be put } = 1\cdot 33553107\,(1 + \cdot 00001000\,u_5),$$

$$\text{and } - \cdot 74876579\,(1 + \downarrow [u'_5 \ldots) \text{ may be put } = - \cdot 74876579\,(1 + \cdot 00001000\,u_5):$$

$$\therefore \quad \epsilon^{z_1} - \frac{1}{\epsilon^{z_1}} = \cdot 58675628 + 2\cdot 08429686\,(\cdot 00001000\,u_5) \qquad \begin{array}{r|l} 2\cdot 0842 & 9686 \\ \hline & 2084 \end{array}$$

$$\therefore \quad \cdot 58675628 + \cdot 00002084\,u_5 = \cdot 50682320 + \cdot 00001116\,u_5 \qquad \therefore \quad u_5 = \frac{5792}{968} = 5\cdot 983$$

$$10^8\,z = \downarrow, 3, 0, 3, 4, 5, 9, 8, 3, = 28938887, \qquad \therefore \quad z = \frac{1}{2\,v} = \cdot 2893887$$

$\therefore\ v = 1\cdot 72777897$ true to the last figure, when $y = 1$; $\quad\therefore$ when $y = 53\cdot 1$, $v = 91\cdot 745063$ ft.

From [1], $s^2 = x\,(x + 2\,v) = 15\cdot 8\,(15\cdot 8 + 183\cdot 490126) \quad \therefore\ s = 56\cdot 11395$

$\therefore$ the length of the whole curve, Q O H, Fig. 1570, is $112\cdot 2279$ ft. $\quad x + v = 107\cdot 545$ ft.

Tension at the lowest part $= 91\cdot 745 \times 20 = 1834\cdot 9$ lbs.

Tensions at points of suspension $= 107\cdot 545 \times 20 = 2150\cdot 9$ lbs.

Ques.—The length of a heavy flexihle chain A O B, Fig. 1570, is just double the horizontal line A B, joining the points of suspension A and B; required the pressure on these points and the tension at the lowest point O; the distance of O from tho horizontal line A B is also required.

If A X = 1, the length of half the curve, or A Q O, = 2, and eqnation [4], becomes

$$2 = \frac{v}{2}\left(\epsilon^{\frac{1}{v}} - \frac{1}{\epsilon^{\frac{1}{v}}}\right);\ \text{and pntting } z = \frac{1}{v}\ \epsilon^z - \frac{1}{\epsilon^z} = 4\,z.$$

When $z = 2\cdot$ the dnal logarithm of ϵ^z is nearly = the dual log. of $8\cdot$; $4\,z = 8\cdot$ also. It may be remarked here that, in operating with the dual calculns, we may take dual digits much greater or much less than any particular one pointed out, and yet obtain, without tentative artifices, a result as near the truth as we please. Since this method gives the same result as near the truth as we please, hy several direct processes, it presents a series of direct operations, and not a succession of approximate trials.

$\downarrow, (7\cdot 38905604) = 200000000$, and $\downarrow, (\cdot 13533528) = '200000000$; conseqnently we may assume

$$7\cdot 38905604\,(1 + \downarrow [u_1 \ldots) - \cdot 13533528\,(1 + \downarrow [u'_1 \ldots) = 4\,(2\cdot 200000000 + \cdot 09531018\,u_1);\ \text{(A)}$$

200000000, is increased hy 9531018, for every unit in u_1; and $2\cdot 00000000$ by $\cdot 09531018$.

To find a convenient value for u_1, (A) may become

$$7\cdot 25372076 + 7\cdot 52439132\,\frac{u_1}{10} = 8\cdot 00000000 + \cdot 38124072\,u_1$$

$$\therefore\ \cdot 37119841\,u_1 = \cdot 74627924 \qquad \therefore\ u_1 = +\,2 \text{ or } \downarrow 2,$$

In practice, one-tenth of the figures here employed would not be required to find that $\downarrow 2,$ is a convenient value for u_1. This may be too great, but that is of no consequence, as the next digit may be negative to compensate for the excess in taking

$$u_1 = \downarrow 2,\ 200000000,\ +\ 19062036,\ = \downarrow_{,} (8\cdot 94075744) \text{ and } {}'219062036 = \downarrow_{,} (\cdot 11184734).$$

To find a convenient value of u_2, the equation now takes the form,

$$8\cdot 96075744\ (1 + \downarrow [u_2 \ldots) - \cdot 11184734\ (1 + \uparrow [u_2 \ldots) = 4\ (2\cdot 19062136 + \cdot 00995033\, u_2);$$

$$\text{therefore we may put } 8\cdot 82891010 + 9\cdot 05260478 \frac{u_2}{100} = 8\cdot 76248144 + \cdot 03980132\, u_2$$

$$\therefore\ u_{2,} = -1\cdot \text{ or } = \downarrow 0,\ '1.$$

For every unit in u_2, we employ 995033, and $\cdot 00995033$; but for every unit in $'u_2$ we employ $'1005034$ and $- \cdot 01005034$.

$$\begin{array}{l} 219062036, \\ \ \ '1005034 \\ \hline 218057002, = \downarrow_{,} (8\cdot 85134984); \qquad '218057002 = \downarrow_{,} (\cdot 112977175) \end{array}$$

$$\therefore\ 8\cdot 85134984\ (1 \downarrow [u_3) - \cdot 11297718\ (1 + \uparrow [u_3 \ldots) = 4\ (2\cdot 18057002 + \cdot 00099950\, u_3)$$

$$\text{This gives } u_3 = -3 \text{ or } \downarrow '0\ '0\ '3$$

This process being continued gives $z = 2 \downarrow 2, '1\ '3\ '3\ 5, 0, 5, 2,$ the log of ϵ^z is 217731902, for $\downarrow_{,} 2, '1\ '3\ '3\ 5, 0, 5, 2,$ Putting B for the base $1\cdot 00000001$, then $B^{217731902} = \epsilon^{2\cdot 17731902}$.

The reciprocal of $2\cdot 17731902 = \cdot 45928042 = v$, the length of chain which is = tension at O.

But as $x^2 + 2\,e\,x = s^2$; $x = 1\cdot 592779 = $ X O.

$x + s = 2\cdot 052059 =$ the length of the chain that amounts to the tension at A and B.

Ques.—Given the length of a heavy flexible chain R Q O H N = 1130 ft. (2 a), Fig. 1570; this chain hangs freely over two pulleys Q, H in the same horizontal line Q H, = 226 ft. (2 b); required the position in which it will rest, the length of Q R, and the length of chain that is equal to the tension at O. Let Q E : O Q R :: 1 : n or $b : a :: 1 : n$. It is evident that when the chain is in a state of rest, what in the foregoing questions was the pressure on the points of suspension Q, H, will be equal to the weight of either H N or of Q R $= x + e$, the parts hanging vertically. Putting $s =$ the length of Q O, when Q E $= 1 = y$; O Q R $= n$; and Q F = E O $= x$, then $x + e + s = n$; $v =$ F R = O C.

$$\left.\begin{array}{ll} \text{From [3].} & x + v = \dfrac{v}{2}\left(\epsilon^{\frac{1}{v}} + \dfrac{1}{\epsilon^{\frac{1}{v}}}\right) \\[2ex] \text{From [4].} & s = \dfrac{v}{2}\left(\epsilon^{\frac{1}{v}} - \dfrac{1}{\epsilon^{\frac{1}{v}}}\right) \end{array}\right\}, \text{ since } y = 1.$$

Whence, from adding these equations together we obtain $x + e + s = n = v\,\epsilon^{\frac{1}{v}}$

$$\therefore\ \downarrow_{,} n = \downarrow_{,} v + \downarrow_{,}\left(\epsilon^{\frac{1}{v}}\right) = \downarrow_{,} v + \frac{1}{e}\downarrow_{,}\epsilon \quad \therefore\ v \downarrow_{,} n = e \downarrow_{,} v + \downarrow_{,}\epsilon \quad \therefore\ e \downarrow_{,} n - \downarrow_{,}\epsilon = e \downarrow_{,} v$$

$$\text{or } \frac{n^v}{\epsilon} = v^v \text{ or } \frac{1}{\epsilon} = \left(\frac{v}{n}\right)^v$$

Taking the $\frac{1}{n}$ root of both sides of the last equation we obtain an equation easily solved by the dual method. $\left(\frac{1}{\epsilon}\right)^{\frac{1}{n}} = \left(\frac{v}{n}\right)^{\frac{v}{n}} = z^z$, putting z for $\frac{v}{n}$

Hence we have the final equation $z^z = \left(\frac{1}{\epsilon}\right)^{\frac{1}{n}}$, or $z \downarrow_{,} z = \downarrow_{,}\left(\frac{1}{\epsilon}\right)^{\frac{1}{n}} = \frac{1}{n}\downarrow_{,}\left(\frac{1}{\epsilon}\right)$.

Before the introduction of dual arithmetic, independent and direct solutions of equations of the above forms could not be effected.

$$\downarrow_{,}\left(\frac{1}{\epsilon}\right) = {}'100000000; \text{ and } \frac{1}{n} = \frac{1}{5} = \frac{b}{a}; \quad \therefore\ z \downarrow_{,} z = {}'20000000.$$

$\therefore\ z = \frac{1}{12} \downarrow 0, '6\ 2, 5, 6, 8, 3, 3, = \cdot 078658307$; $\therefore\ v = \cdot 393291535$, see Byrne's 'Essential Elements of Practical Mechanics,' p. 124. The value of $z, = \frac{v}{n}$, not attainable by any previously known method, may be almost instantly obtained under a variety of forms by the dual calculus to any required degree of accuracy. In the present case,

$$z = \frac{1}{12} \downarrow '0\ '6\ 2, 5, 6, 8, 3, 3, 1, 7,; \quad z = \frac{1}{20} \downarrow 4, 7, 2, 1, 9, 8, 2, 2, = \cdot 078658307, \text{ and so on.}$$

Under the last form all the dual digits are positive.

$$\downarrow_{,}\left(\frac{e}{n}\right) = {}'254264202 \quad \therefore\ \downarrow_{,}\left(\frac{n}{e}\right) = 254264202,$$

$$\therefore\ \frac{n}{e} = 12\cdot 7132147; \text{ and hence } \frac{1}{e} = 2\cdot 54264294.$$

But we have before shown that

$$n = v\,\epsilon^{\frac{1}{v}} \quad \therefore\ \downarrow,\left(\frac{n}{v}\right) = \downarrow,\left(\epsilon^{\frac{1}{v}}\right) = 254264202, \text{ and } \downarrow,\left(\frac{1}{\epsilon^{\frac{1}{v}}}\right) = {}'254264202;$$

$$\text{Whence } s = \frac{v}{2}\left(\epsilon^{\frac{1}{v}} - \frac{1}{\epsilon^{\frac{1}{v}}}\right) \text{ becomes known.}$$

$$s = \frac{v}{2}\,(12{\cdot}7132147 - {\cdot}078658307) = ({\cdot}393291535 \times 6{\cdot}3172782) = 2{\cdot}48448448;$$

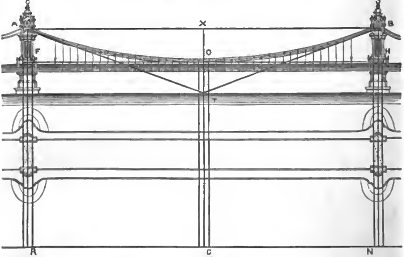
$$\text{Because, } x + v + s = n = 5. \quad \therefore\ x = 2{\cdot}12222398.$$

In these calculations, Q E = y is put = 1; but in the question, Q E = 113 ft.

$\therefore$ $x = 239{\cdot}8113097$ ft. = E O = Q F; $s = 280{\cdot}74675$ ft. = arc Q O; and $v = 44{\cdot}441966$ ft. = F R = O C = the length of chain that is equal to the tension at O. $v + x = 284{\cdot}253254$ ft. = Q R = the length corresponding to the tension at Q or H.

Ques.—In the Chelsea Suspension Bridge, Thomas Page, engineer, the central span between the piers is 348 ft. with a deflection O X, Fig. 1571, of 29 ft.; supposing the entire weight of the

1571.



1572.

chain A O B, when the weight of the platform, roadway, and full load is transferred to it, to be 1·5 ton for each foot of its length, required the strains at the highest points A and B, and the tension at the lowest point O, as well as the length of the catenary curve passing through the points A, O, B.

$$\frac{348}{2} = 174;\ \frac{29}{174} = \frac{1}{6} = c^2 \quad \therefore\ 2c = {\cdot}81649658.$$

Whence equation [5] becomes

$${\cdot}81649658\sqrt{z} = \epsilon^z - \frac{1}{\epsilon^z} = 2c\sqrt{z}; \qquad [a]$$

z being put for $\frac{1}{2v}$; v representing the length of the chain, whose weight is equal to the tension at the lowest point O.

We propose to find the value of v under the form $\downarrow u_1 u_2 u_3 \ldots$ To find a convenient value for u_1, assume $z = \downarrow u_1$, then [a] gives

$$(1 + \downarrow [u_1, \ldots) - (1 + \uparrow [{}'u_1 \ldots) = 2c\sqrt{z} = 2c\sqrt{u_1 \times {\cdot}09531018}$$

9531010, being the dual of a logarithm of $\downarrow 1$, or of each unit in u_1. Since we arrive at the exact value of z, whether we assume u_1 too great or too small,

$$(1 + [u_1) - (1 - [u_1) = +\,2\,\frac{u_1}{10} \text{ may be put } = 2c\sqrt{u_1 \times {\cdot}09531018}$$

$$\therefore\ \frac{u_1^{\,2}}{100} = c^2\,(u_1 \times {\cdot}09531018) = \frac{1}{6}\,(u_1 \times {\cdot}09531018).$$

$$\therefore\ u_1 = \frac{9{\cdot}531018}{6} = 1{\cdot}59.$$

$\therefore$ The reciprocal of u_1, or $'u_1$ may be put $= \downarrow {'1}\,{'5}\,{'9}\ \ldots\ldots$ or $u_{1} = \downarrow 1, 7,$

$$\downarrow, (1{\cdot}17934889) = \downarrow, 1, 7, 0, 0, 0, 0, 0, 0, = 16496249,$$

$$\text{Reciprocal} = {'16496249} = \downarrow, {'1}\,{'5}\,{'9}\,{'3}\,{'4}\,{'5}\,{'7}\,{'7} = \downarrow, ({\cdot}84792554).$$

It is easily found that o, is the most convenient value for u_3, hence we may put in [a]

$$z = \downarrow 1, 7, 0, u_4,$$

$$\therefore \epsilon^z - \frac{1}{\epsilon^z} = 2c\sqrt{{\cdot}16496249 + {\cdot}00010000\,u_4}$$

$$= 2c\sqrt{{\cdot}16496219}\,(1 + {\cdot}00030310\,u_4) = {\cdot}33162478\,(1 + {\cdot}00030310\,u_4);$$

$\epsilon^z - \dfrac{1}{\epsilon^z}$ may also be put under the form

$$1{\cdot}17934889\,(1 + \downarrow [u_4, \ldots) - {\cdot}84792554\,(1 + \uparrow [{'u_4} \ldots) = (1{\cdot}17934889)\,(1 + {\cdot}00010000\,u_4)$$
$$- ({\cdot}84792554)\,(1 - {\cdot}00010000\,u_4) = {\cdot}33142335 + {\cdot}00020373\,u_4$$

$$\therefore {\cdot}33142335 + {\cdot}00020373\,u_4 = {\cdot}33162478\,(1 + {\cdot}00030310\,u_4) = {\cdot}33162478 + {\cdot}00010052\,u_4$$

$$\therefore u_4 = \frac{{\cdot}00020143}{{\cdot}00010052} = \frac{20143}{19052} = 1{\cdot}952$$

$\therefore z$ may be again put $= \downarrow 1, 7, 0, 1, 9, u_6$, when a greater degree of accuracy is required.

$$\downarrow, (1{\cdot}17957297) = \downarrow, 1, 7, 0, 1, 9, 0, 0, 0, = 16515249,$$

$$\text{Reciprocal}, {'16515249} = \downarrow, {'1}\,{'5}\,{'9}\,{'5}\,{'3}\,{'6}\,{'2}\,{'1} = \downarrow, ({\cdot}84776406)$$

$$\begin{array}{r} 1{\cdot}17957297 \\ {\cdot}84776406 \\ \hline {\cdot}33180891 \end{array} \qquad\qquad \begin{array}{r|l} \multicolumn{2}{r}{1{\cdot}17957297} \\ \multicolumn{2}{r}{{\cdot}84776406} \\ \hline 2{\cdot}02733 & 703 \\ \hline {\cdot}00000 & 203\,u_6 \end{array}$$

$$2c\sqrt{{\cdot}16515249 + {\cdot}00000100\,u_6} = 2c\sqrt{{\cdot}16515249}\,(1 + {\cdot}00000303\,u_6)$$
$$= {\cdot}33181570\,(1 + {\cdot}00000303\,u_6)$$

$$\therefore {\cdot}33180891 + {\cdot}00000203\,u_6 = {\cdot}33181570 + {\cdot}00000101\,u_6$$

$$\therefore u_6 = \frac{{\cdot}00000679}{{\cdot}00000102} = \frac{679}{102} = 6{\cdot}66 \quad \therefore \downarrow, z = \downarrow, 1, 7, 0, 1, 9, 6, 6, 6, = 16515915,$$

$$\text{or } \epsilon^{{\cdot}16515915} - \frac{1}{\epsilon^{{\cdot}16515915}} = ({\cdot}81649658)\sqrt{{\cdot}16515915}.$$

To find the value of z in such equations as [a], to any required degree of accuracy, and by such direct, independent, and simple means, is, without doubt, a great mathematical achievement.

$$z = \frac{1}{2v} \quad \therefore v = 3{\cdot}02738298 = \text{three times the length of O C.}$$

$x + v = 3{\cdot}19404964$; and the length of the catenary curve passing through the points A, O, $= \sqrt{x^2 + 2vx}$, [1];

$\therefore$ the length of the curve A O $= 1{\cdot}01828555$. But when A X = 174 ft., then $v = 526{\cdot}7646$ ft.; $x + v = 555{\cdot}7646$ ft.; and the length of the catenary curve passing through the points A, O, B, $= 354{\cdot}36337$ ft. $(526{\cdot}7646) \times (1{\cdot}5) = 790{\cdot}1468$ tons, the tension at the lowest point O in the direction of the tangent O F, and represented by the lengths of the three lines O C, Fig. 1572. $(555{\cdot}7646 \times (1{\cdot}5) = 833{\cdot}6469$ tons, the tension at the highest point A, but in the direction of the tangent A T; this tension is represented by the lengths of the three lines F R, and the line A F. The sectional area at the centre of the bridge = 214 sq. in. and the sectional area at A and B = 230 sq. in.; hence a weight of only 5 tons to the sq. in. gives a power at O of 1070 tons, and at A and B a power to sustain a tension of 1150 tons with ease.

Comparative merits of different Systems of Iron Bridge Building accurately examined. *Taken from Jules Gaudard's excellent work, 'Étude Comparative de Divers Systèmes de Ponts en Fer.'*

General Symbols.

- M = Moment of rupture, or moment of resistance which is equal to it;
- F = Stress or transverse strain;
- R = Resistance the square mètre (6000000 for tension or compression, 4000000 for shearing strain) (see No. 18);
- p = Permanent continuous load, the lineal mètre of girder;
- p' = Moving load, the lineal mètre of girder;
- q = Proportion $\dfrac{p'}{p + p'}$ of the moving to the whole load;
- P = Sometimes a weight applied to a certain point of a girder, sometimes the weight of the girder itself in its length of bearing;
- l = Bearing of the girder;
- L = Length of the girder;
- $\dfrac{P}{l}$ = Mean weight of girder, the lineal mètre (see No. 37);
- $\dfrac{PL}{l}$ = Weight of the girder;
- d = Void between the abutments;
- $\dfrac{PL}{ld}$ = Weight the lineal mètre of girder spanning the void;
- δ = Interval between two successive points to which the load is applied, in girders loaded in a discontinuous manner;

$N = \frac{l}{\delta}$;

$m = \frac{l}{2\delta}$ or $\frac{l-\delta}{2\delta}$, according as δ enters an even or an odd number of times into l;

n = Number indicating the order of a section of flange or a lattice-bar, the numbering beginning at the middle of the bearing;

α = Angle of inclination of the struts;

β = Angle of inclination of the ties;

h = Height of the girder;

t = Weight the lineal mètre of a prism capable of supporting a strain of 1 kilogramme, or proportion of the weight of a cubic mètre to the resistance per square mètre. For iron $t = \frac{7800^k}{6000000} = 0 \cdot 0013$;

U = Coefficient applied to the flanges, the actual weight of which is always greater than the theoretical weight (see Nos. 63 and following);

V = Mean coefficient of stiffness applied to compressed bars (see Nos. 68 and following);

Ω = Supplementary term taking into account the weight of various accessories independent of h.

The dimensions of an iron plate are denoted by the symbol a/b, the letters a and b being replaced by numbers indicating respectively the breadth and the thickness of the section.

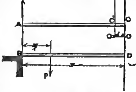
For an angle-iron, we write $a/b/c$ or $\frac{a/b}{c}$, a and b being the breadth of the arms, and c the mean thickness; for a simple T, $\frac{a/b}{c/d}$, a being the total breadth of the double arm and c its thickness, b the length of the single arm (including the thickness c), and d its thickness.

For a double T rolled, $\frac{a/b}{c/d}$, a being the total height, c the thickness of the web, b the breadth of the flanges, and d their thickness; and, generally, for a double T, consisting of plate and angle iron, we indicate successively the dimensions of the web, one of the four angle-irons, and one of the flanges.

When angle-iron with arms of unequal length is used, the lesser arm is applied to the plate and bears the bolts, and the greater forms the projecting mouldings or flanges.

1. *Moments of Rupture and Transverse Strain for Girders resting freely upon Two Supports.*—Let us consider, Figs. 1573, 1574, a portion A B C D of a girder included between any section C D and a support B, and subjected to various loads or vertical forces, as P. The reaction of the abutment is a force R also vertical. The reactions exerted at C D may be reduced to a force F and a couple. The other forces being vertical, F must be vertical also: it is in equilibrio with the vertical transverse strain in the section considered, the value of which is $F = R - \Sigma P$, the sign Σ indicating a sum. The condition of equilibrium relative to the moments of the forces requires that the moment of the couple, or *moment of resistance* of the section C D, should be equal to the moment of the other forces with respect to this same section. This latter moment, called *moment of rupture*, has the value $M = R\,x - \Sigma\,P\,(x - x_1)$. Its differential $\frac{d\,M}{d\,x} = R - \Sigma\,P$ = transverse strain.

1573.



1574.

The vertical rib, or web of the girder, is besides subjected to a sliding strain upon its longitudinal fibres or horizontal transverse strain. Indeed, if we conceive the fragment C O O′ C′, limited by two sections infinitely near C O, C′ O′, and by a horizontal fibre O O′, this fragment is subjected, upon C O, to a certain pressure T, and upon C′ O′ to T + d T: the resultant d T ought to be held in equilibrio by a force of adhesion $R_1\,e\,d\,x$ upon O O′ (e = thickness of the web, R_1 = resistance to shearing strain.

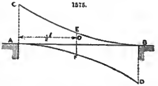
The maximum of this action occurs when O O′ is situate upon the neutral axis; for then T is resisted by the force of all the compressed fibres situate above this axis. As the flange has a section usually greater than the rib, and, besides this, contains the fibres which are most acted upon, the point of application of the resultant T will be very near the flange, and its value will be approximatively equal to the moment of rupture M divided by the height h of the girder. Consequently we shall have $d\,T = \frac{d\,M}{h} = R_1\,e\,d\,x$, whence $e = \frac{d\,M}{d\,x} \cdot \frac{1}{R_1\,h} = \frac{F}{R_1\,h}$, which may be explained by saying that the vertical section $e\,h$ of the rib should be capable of resisting a shearing force equal to the transverse strain, a condition which enables us to calculate the thickness e.

2. *Moment of Rupture and Transverse Strain due to a Load uniformly distributed.*—If the load p per lineal mètre extends throughout the whole length of bearing l, the figure of the moments of rupture will be the parabola $M = \frac{1}{2}\,p\,x\,(l - x)$, the abscissæ being reckoned from the abutment. This parabola has its axis vertical, and the value of its parameter is $\frac{2}{p}$; the maximum moment in the middle of the bearing is $\frac{p\,l^2}{8}$. The transverse strain is represented by the right line having

for equation $F = p\left(\frac{l}{2} - x\right)$; it is $= 0$ in the middle of the bearing. Considering the beginning of the co-ordinates in the middle of the girder, we should have $M = \frac{p}{2}\left(\frac{l^2}{4} - x'^2\right)$ and $F = -p x'$.

3. Let us now consider a load p' per lineal mètre, uniformly distributed as p, but extending only over a portion of the bearing included between the fixed abscissæ $x = a$, and $x = a + b$, reckoned from the left abutment. Then, in the first interval, of length a, the moment of rupture due to p' will be represented by a right line $M = \frac{p' b}{2 l}(2 l - 2 a - b) x$; in the second interval, of length b, by an arc of a parabola tangential to the preceding right line, and expressed by $M = \frac{p' b}{2 l}(2 l - 2 a - b) x - \frac{1}{2} p' (x - a)^2$; and in the third interval, of length $l - a - b$, by a new tangent to the parabola, namely, $M = \frac{p' b (2 a + b)}{2 l} (l - x)$. The figure of the transverse strains is a broken line, the extreme portions of which are horizontal.

For the maximum of the moment of rupture p' must extend over the whole bearing; but for the maximum of strain at the point, the abscissa of which is x, p' must lie only between this point and the most distant support. If it lies between the point in question and the right abutment, the force is positive, if we consider as positive those forces which act upwards; it is expressed by $F = \frac{p'}{2 l} (l - x)^2$, and is consequently represented by an arc of a parabola, the ordinate of which upon the left support is $A C = \frac{p' l}{2}$, Fig. 1575, the ordinate in the middle $O E = \frac{p' l}{8}$, and the ordinate at $B = 0$; this latter point is the summit of the parabola. When, on the contrary, the load is placed upon the length included between A and the point the abscissa of which is x, we have as the figure of the straining forces, then negative, another parabola A F D, having its summit in A, and the maximum ordinate of which, absolutely expressed, is $- B D = -\frac{p' l}{2}$. Thus the load p', by changing its position, produces at each point of the bearing transverse strains sometimes positive, sometimes negative.



1575.

4. In brief, if we have at the same time a dead weight p and a moving weight p', the maximum moment of rupture will be $M = \frac{1}{2} (p + p') x (l - x)$, and the transverse strain in the left half bay $F = \frac{1}{2}(p + p')(l - 2 x) + \frac{p' x^2}{2 l} = \frac{1}{2}(p + p')\left(l - 2 x + \frac{x^2}{l} q\right)$, q denoting the proportion of the moving weight p' to the total weight $p + p'$.

The value of the area comprised between the figure of the moments of rupture and the axis of the x's is $\frac{1}{12} (p + p') l^3$, and the area of the maximum straining forces, absolutely expressed, is $\frac{1}{4} (p + p') l^2 \left(1 + \frac{1}{6} q\right)$ for the whole bearing. Dividing these areas by l, we shall have the mean ordinates of the moments of rupture and of the maximum straining forces. Sometimes the effects do not depend exclusively upon F or M, but upon a function of the form B F − A M. Now if we consider only p', this function will be greatest when p' extends between the point considered and the farthest abutment; it will then attain the value $\frac{p' (l - x)^2}{2 l} (B - A x)$.

5. *Effect of Loads uniformly distributed at certain intervals.*—When a girder supports discontinuous weights P, P′ P″, . . . applied to points having as their abscissæ a, $a + b$, $a + b + c$, and so on, and such that $P = \frac{1}{2} p (a + b)$, $P' = \frac{1}{2} p (b + c)$, and so on, the figure of the moments of rupture is a polygon inscribed in the parabola which would correspond with a load p per lineal mètre, uniformly distributed over all the parts of the girder.

Supposing each of the extreme intervals equal to a, all the intermediate intervals to δ, and $l = 2 a + N \delta$, the permanent weights applied to the points of division will be equal to $p \delta$, except at the extreme points, where they will be $\frac{1}{2} p (a + \delta)$. The load p' will furnish analogous weights, but they can be only on a certain number of consecutive points of division. The transverse strain for a given load is constant in each interval, but varies from one to the other. In order that it may reach its maximum in the interval preceding the point having as its abscissa $a + \kappa \delta$, the load must be applied to this point and to all those which follow it, as far as the right abutment, the point in question being supposed on the left of the middle of the girder. We shall thus obtain for this maximum,

$$F = \frac{\delta}{2} (p + p') (N - 2 \kappa + 1) \left[1 + \frac{\kappa (\kappa - 1) \delta^2 + a (2 \kappa \delta - \delta + a)}{\delta (N \delta + 2 a) (N - 2 \kappa + 1)} q\right];$$

but this formula does not apply when $\kappa = 0$, that is for the extreme interval; in that case we have $F = \frac{1}{2} (p + p') (N \delta + a)$.

6. Usually all the intervals are equal to each other. Making, therefore, $a = 0$, and $l = N\,\delta$, we shall have $F = \frac{\delta}{2}(p + p')\,(N - 2\,\kappa + 1)\left[1 + \frac{\kappa\,(\kappa - 1)}{N\,(N - 2\,\kappa + 1)}\,q\right]$ in the interval included between the abscissæ $(\kappa - 1)\,\delta$ and $\kappa\,\delta$. This formula holds good for the first interval.

To find the sum of the values of the transverse strain in all the intervals when N is an even number, take the sum of the preceding expression in which κ assumes the successive values $1, 2, \frac{N}{2}$, and double the result for the whole bearing. We thus obtain

$$\Sigma\,F = (p + p')\,\frac{N\,l}{4}\left(1 + \frac{N^2 - 4}{6\,N^2}\,q\right),$$

and multiplying by δ we shall have the area of the polygon of the maximum straining forces absolutely considered. When N is an odd number, find the sum on the supposition that κ varies from 1 to $\frac{N-1}{2}$, double the result, and add the force of the middle interval which will correspond with $\kappa = \frac{N+1}{2}$. We thus obtain $\Sigma\,F = (p + p')\,l\,\frac{N^2 - 1}{4\,N}\left(1 + \frac{1}{6}\,q\right)$.

The area of the polygon of the moments of rupture may be found by taking from the area of the circumscribed parabola N small segments, the chords of which have each δ as a horizontal projection, and the surfaces of which have the constant value $\frac{1}{12}(p + p')\,\delta^3$. We thus obtain for the area sought $(p + p')\,l^3\,\frac{N^2 - 1}{12\,N^2}$, a formula which applies whether N be an even or an odd number. We should have $\frac{1}{12}(p + p')\,(l^3 - N\,\delta^3 - 2\,a^3)$ in the more general case in which $l = 2\,a + N\,\delta$.

7. When we have to consider an expression of the form $B\,F - A\,M$, where M denotes the moment of rupture with respect to the point the abscissa of which is $\kappa\,\delta$, and F the force in the interval preceding this point, we shall raise it to its maximum by applying the load to the point the abscissa of which is $\kappa\,\delta$ and to the following points of division as far as the right abutment, $\kappa\,\delta$ being supposed less than $\frac{l}{2}$. We obtain in this way the maxima value

$$\frac{p'\,\delta}{2\,N}\,(N - \kappa)\,(N - \kappa + 1)\,(B - A\,\kappa\,\delta),$$

the term due to the permanent load not included. If, on the contrary, F were the force beyond the point the abscissa of which is $\kappa\,\delta$, to obtain the maximum we should have to suppress the weight at this point, and the formula would then be $\frac{p'\,\delta}{2\,N}\,(N - \kappa)\,(N - \kappa - 1)\,(B - A\,\kappa\,\delta)$.

If the expression considered were of the form $B\,F - A\,M - A'\,M'$, M being the moment at the point the abscissa of which is $\kappa\,\delta$, M' that at the preceding point the abscissa of which is $(\kappa - 1)\,\delta$, and F the force between these two points, this expression would be

$$\frac{p'\,\delta}{2\,N}\,(N - \kappa)\,(N - \kappa + 1)\,[B - A\,\kappa\,\delta - A'\,(\kappa - 1)\,\delta].$$

8. *Moments of Rupture produced by the Passage of a Wheel.*—A weight P applied to the point the abscissa of which is a, reckoning from the abutment, would produce moments of rupture represented by two right lines beginning at the supports and meeting at the loaded point where the ordinate reaches the value $\frac{P\,a\,(l - a)}{l}$. But if this weight P be a wheel rolling from one end of the bearing to the other, the maximum moment at any given point will be produced when the wheel is passing over this point, and the maximum moments will be the parabola having the equation $M = \frac{P\,x\,(l - x)}{l}$ and the parameter $\frac{l}{P}$.

If the girder support besides a uniform load P per lineal mètre, it will be sufficient to substitute for P in the preceding equation $P + \frac{p\,l}{2}$.

But the parabola representing the moments due to P is only an imaginary one, since at any given instant there exists only one of its points, the one determined by the ordinate on the right of the load; and the moments of rupture at this instant are the broken line of which we have already spoken. The force F is also not derived from the parabola, but the inclination of one or the other of the right lines composing the broken line, according as we wish to find the force on one side or the other of the section considered.

9. *Moments of Rupture produced by Two Wheels.*—The two wheels occupying a determinate position, the moments of rupture are a broken line composed of three right lines. But to have at a given point the maximum moment we must bring one of the wheels of the vehicle upon it, the other wheel so placing itself that their common distance d remains constant. If the left wheel P be placed upon the point the abscissa of which is x, the moment of rupture will be $M = \frac{x}{l}\,[Q\,(l - x) - P'\,d]$, Q representing the quantity $P + P' + \frac{p\,l}{2}$, on the hypothesis that the girder supports besides a permanent load p a lineal mètre.

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